N73-23837
CR-128920

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

STUDY PHASE

FINAL REPORT

NASA CONTRACT NAS 9-10748

January 1973 Vol. 3 of 3

CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CSR-TR-73-1

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

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NASA CONTRACT NAS 9-10748

January 1973

Vol. 3 of 3

APPENDIX 6.3

NASA EXPERIMENTS RELIABILITY AND QUALITY OPERATING PROCEDURES

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

MIT/DL

NASA EXPERIMENTS

RELIABILITY and QUALITY OPERATING PROCEDURES

June 1970

APPENDIX I

MIT CHARLES STARK DRAPER LABORATORY

CAMBRIDGE, MASSACHUSETTS, 02139

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LIST OF ILLUSTRATIONS

INTRODUCTION

It is the purpose of this document to provide the NASA with visibility into the Reliability and Quality Assurance system and procedures which will be implemented by MIT on the two Lunar Experiment Projects. From a quality point of view, both the Surface Electrical Properties and Gravimeter Experiments will be handled in an identical fashion with as much commonality of personnel and facilities as is possible.

The Quality System defined herein is the standard system developed at MIT for implementation in an Engineering Research and Development Environment. It is adhered to at MIT on all projects where delivery of hardware destined for flight or sponsor use is a contractual requirement. It should be noted that certain procedures have been modified and new ones added to the basic MIT system in order to be responsive to NASA requirements and adapt to the special needs as dictated by the nature of the experiment projects.

This system is designed to provide the NASA with a high degree of confidence that our design and product, as represented by the hardware which will be delivered to NASA, is of known and documented quality and free of problems associated with workmanship defects. This system, as defined in the succeeding procedures, provides for the accomplishment of the following quality objectives:

1. That the design is reviewed for engineering excellence, quality, and reliability; and is subsequently controlled.

2. That parts and materials are procured from quality sources under appropriate quality requirements and that significant characteristics of this procured material are verified by inspection.

3. That material destined for inclusion in deliverable hardware is controlled and traceability maintained as to its history and status.

4. That fabrication and assembly operations are conducted in an organized and orderly fashion, with quality inspection of important hardware characteristics and workmanship, and that documented evidence exists of fabrication operations and inspections performed on hardware as it is processed.

5. That non-conforming, discrepant material, and problems encountered throughout the process are documented, resolved, and corrective action effected.

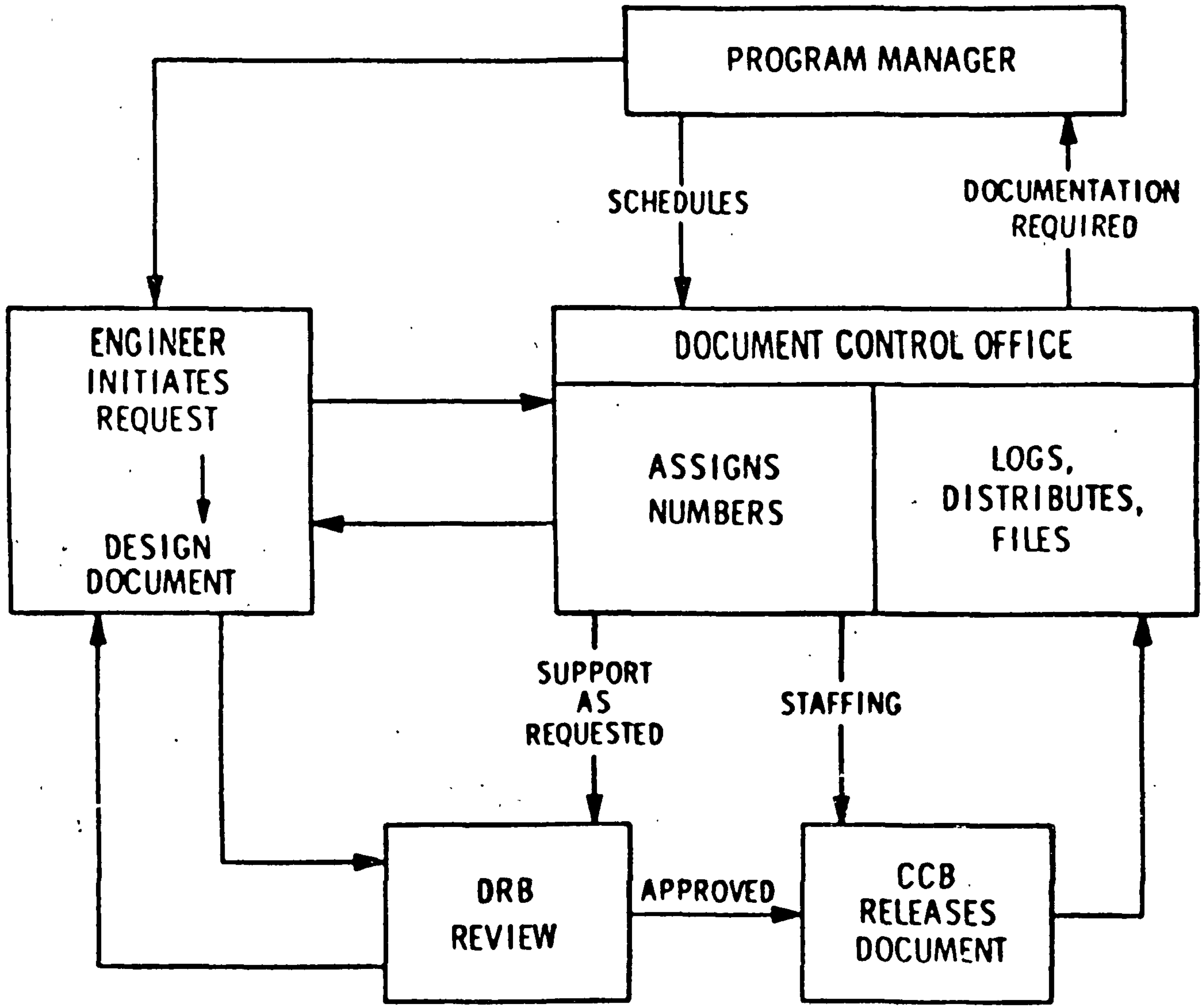
6. That hardware configuration, test data, and history, important to the sponsor's acceptance and use, are accumulated and delivered with the units or collected for future availability.

Aspects of this system are being implemented now and will continue towards full implementation. Subsequent changes, modifications, or new procedures required as the lunar experiment projects mature will be accomplished and incorporated into the system by memorandum, addendum, or revision to the affected QOP applicable. Comments received from NASA as of the date of this publication have been incorporated.

TITLE DOCUMENTATION CONTROL	NUMBER QOP 001		
	ISSUED May 13, 1970		
	REVISED	SHEET 1 OF 2	

The Control of Documentation, release of engineering drawings, changes thereto, the change control board, and configuration management is defined for the NASA Experiment Programs in MIT/DL Report E-2509 (Configuration Management Plan).

For procedures governing these operations, refer to the above plan. The general flow of documentation is as shown in Figure 1.



Design Documentation Flow Diagram

Fig. 1.1

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 002	
DESIGN REVIEW	ISSUED October, 1969	
	REVISED June 9, 1970	SHEET 1 OF 3

1. Purpose

1.1 It is the purpose of Design Review to provide the maximum assurance, at the earliest possible time, that a design has the required potential for quality and reliability and that areas wherein the design or improvement is possible are defined and acted upon.

1.2 Design Review will provide the opportunity for, and bring to bear, the best technical competence available within the project in consideration of a given design at an appropriate time in its development.

1.3 Design Review will focus management attention on the adequacy of design approach and problems at an early stage of design development, and prior to the release of drawings to manufacture.

1.4 Design Review shall take cognizance of the necessity of experiment hardware to be "man-rated". While experiment hardware is not directly related to the success of a lunar mission or crew safety, it must be of such a design and configuration as not to endanger the mission by influence on other spacecraft systems or the spacecraft environment nor shall there be any potential areas of hazard to the crew when they are utilizing the hardware.

2. Scope

2.1 There shall be at least three design reviews for every project.

2.1.1 Conceptual Design Review: A review of the proposed design and design approach at the onset or at an appropriate time during the definition phase of each project.

2.1.2 Design Documentation Review: A review of the drawings and specifications necessary to the manufacture of the hardware at the time of its initial release to procurement or production.

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2.1.3 Change Review: A review of modifications to design documentation where such changes will have an effect on performance, interfaces, interchangeability, life, or reliability (Class 1 changes).

3. Design Review Considerations

3.1 Each design review shall consider the design carefully and in detail from the following standpoints.

Reliability	Function & Operability
Maintainability	Interfaces
Compatibility	Integration
Producibility	Mechanical Integrity
Optimization	Parts Application
Cost	Environmental Capability
Safety	Material Usage
Quality	

3.2 Materials Compatibility

3.2.1 Prior to or at the design review, all materials interfacing with the cabin and lunar surface environment shall be identified and listed with respective areas and weights exposed.

3.2.2 Above materials will be judged for their characteristics of toxicity, flammability, out-gassing, and dissimilar metals.

3.2.3 Each material will be "qualified" by comparison with NASA approved materials lists other acceptable data sources, or tested if data not available.

3.2.4 Materials not conforming to space flight requirements will be eliminated from the design.

4. Design Review Participation

4.1 Participants in Design Review shall be

4.1.1 Project Technical Director or designated representative.

4.1.2 Cognizant Design Engineer

4.1.3 Project R&QA Engineer

4.1.4 Documentation control

4.1.5 Resident NASA Technical Representative (as desired).

4.2 Each of the above shall contribute in the areas of their interest to the review of design and be prepared to discuss all elements of the design.

5. Design Review Reports

5.1 Conceptual Design Reviews shall be documented by memorandum issued by R&QA.

5.2 Design Documentation and Change Reviews shall be documented by the authorizing signature of the Project Technical Director on the appropriate Engineering Release/Change Form and memorandum report, as applicable.

5.3 Design Review memorandum as required shall contain at least the following information, and be prepared and distributed by the Project R&QA Engineer.

5.3.1 Project Name

5.3.2 Documents reviewed

5.3.3 Personnel present or reviewing

5.3.4 Areas of consideration and decisions made

5.3.5 Action items generated and assigned.

5.4 The Project R&QA engineer shall assure action items generated as a result of design review are completed and reported.

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NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE PARTS AND MATERIALS SELECTION, APPLICATION, AND SPECIFICATION	NUMBER QOP 015	
	ISSUED 12-10-69	
	REVISED June 9, 1970	SHEET 1 OF 6

1. Purpose

1.1 It is the purpose of this procedure to:

1.1.1 To use high-reliability parts procured to a one-time buy for all production and qualification systems.

1.1.2 Provide design and engineering groups with a listing of preferred, NASA-acceptable quality components, materials, and suppliers.

1.1.3 Impose standardization of components and materials by a preferred parts list, design review and purchase order approval.

1.1.4 Assure proper application and derating of all parts and materials by preferred parts list, R&QA alert bulletins and design review.

1.1.5 Provide and maintain a list of all non-standard components and materials so selected and incorporated into system design.

1.1.6 Provide for and develop adequate specifications and documentation of non-military components and materials to permit procurement.

1.1.7 Provide for the test and evaluation of new parts and materials under consideration for system application as may be appropriate.

2. Scope

2.1 This procedure shall be applicable to all components and material incorporated into the design of deliverable equipments.

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2.1 Continued
All non-military parts will be documented in the MIT design by the assignment of Specification or Source Control Drawings (SCD's) numbers.

3. Selection and Application

3.1 At the onset of the project design phase, the Project R&QA Engineer shall cause the generation and distribution of a Preferred Parts List.

3.2 The Preferred Parts List will contain the following information.

3.2.1 Military specification number for military parts and materials.

3.2.2 Vendor part numbers for non-military parts and materials.

3.2.3 Part Description.

3.2.4 Approved source or vendor.

3.2.5 Supplier's part number.

3.2.6 Remarks and design notes.

3.2.7 Application notes and derating criteria.

3.3 The Project R&QA Engineer shall perform a liaison function and establish communications between design engineers and R&QA component part specialists. Assistance shall be provided design engineers relating to the selection, application, derating, and identification of special or new non-standard parts.

3.4 Project Design Engineers shall utilize to the maximum extent, high reliability military specification or JAN-TX parts. No non-standard parts shall be selected except through liaison with the Project R&QA Engineer unless they are already listed on the NASA Approved Parts List (NAPL).

3.5 New or special parts and materials under serious consideration for critical applications as mutually determined by the cognizant design engineers and R&QA Component Specialists shall cause a vendor survey or quality audit to be made and the procurement of sample items for evaluation tests. This effort may be initiated at any time by completing a Reliability Request for Engineering Action Form. (See Figure 15.2)

4. Part and Material Specification

4.1 At such time as a non-standard part or material is definitely selected for usage as above, the cognizant design engineer shall prepare and submit to the Project R&QA Engineer a Request for Documentation Form (See Figure 15-1).

4.2 Upon receipt of the Request for Documentation Form, the project R&QA Engineer shall:

4.2.1 Assign a drawing number to the part.

4.2.2 Obtain R&QA signature approval to the request.

4.2.3 Return copy of the approved request form to the design engineer indicative that required procurement documentation preparation is under way and request for NASA approval has been submitted to ROMIT.

4.2.4 Cause preparation of SCD when complexity or criticality of the part requires such documentation.

4.2.5 Coordinate engineering signature approval and release of SCD through the Change Control Board as required.

4.2.6 In the event an SCD is not required, the R&QA engineer shall prepare a procurement package containing all quality, burn-in and screening requirements that must be included on the purchase order.

5. <u>Non-Military Part and Material Usage List</u>

5.1 All non-military parts and materials selected for usage in the design of deliverable equipment shall be listed on the NASA Approved Parts List. (NAPL) Usage approval for these items will be procured from NASA.

5.2 Preparation, maintenance, and distribution of this list shall be the responsibility of the Project R&QA engineer. It will contain the following information:

5.2.1 Drawing number.
5.2.2 Description of the component
5.2.3 Approved supplier
5.2.4 Supplier's Part Number
5.2.5 Drawing preparation status
5.2.6 Qualification status
5.2.7 Design notes or remarks
5.2.8 NASA approval status.

5.3 Receipt and R&QA approval of the Request for Documentation Form shall initiate a listing on NAPL.

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Request No. ____________

Sheet ______ of ______

Date ____________

TO: RELIABILITY AND QUALITY ASSURANCE

.QUEST DOCUMENTATION FOR

NASA EXPERIMENTS

Type of Document ____________ Number ____________

Requesting Engineer(s)	Supervisory Approval	Q.A. Class ______ Dwg. Resp: ______ Neg. Resp: ______	Reliability and Quality Assurance Approval

Unit (Ass'y. Module):

Suggested Title:

Description (briefly of part, process, or procedure):

Vendor(s)	Vendor(s)
Address State	Address State
P/N	P/N

TP# 16082 Rev.

Fig. 15.1

CHARLES STARK DRAPER LABORATORY

RELIABILITY REQUEST FOR ENGINEERING ACTION

NO. ____________

TO: ____________ RM ____________ GROUP ____________

FROM ____________ EXT. ____________

DATE: ____________ PROJECT ____________

SUBJECT: ____________

REQUEST:

SAMPLE

REASON:

REPLY

DOCUMENTS AFFECTED:

EFFECTIVITY (IF APPLICABLE):

DATE: ____________ SIGNATURE ____________

TP7183-5

WHITE TO ADDRESSEE

BLUE FOR: REPLY

PINK RETAINED BY ORIGINATOR

Fig. 15.2

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE		
MATERIAL PROCUREMENT, SUPPLIER AND SUB-CONTRACTOR CONTROL	NUMBER QOP003	
	ISSUED October 1969	
	REVISED June 9, 1970	SHEET 1 OF 4

1. Purpose

1.1 It is the purpose of this procedure to provide assurance that procurement of materials, parts, sub-assemblies and assemblies is initiated only with full consideration and approval by the Project Manager, Manufacturing Manager, and R&QA Engineer.

1.2 It is further the purpose of this procedure to provide assurance that material supplied MIT (particularly that from sub-contractors or major suppliers) is of a uniform quality commensurate with program high-reliability requirements.

2. Scope

2.1 This procedure shall be applicable to the procurement of all hardware elements destined for use in equipment to be delivered to the sponsor.

3. Procurement

3.1 Procurement may be initiated by any authorized project engineer.

3.2 Procurement shall be accomplished as required by normal procurement practices except that the signature approval of the Project Manager, Manufacturing Manager and R&QA engineer shall be required on the purchase order prior to the issuance of that purchase order. In addition, purchase orders exceeding one thousand dollars in value must be signature approved by ROMIT.

3.3 The purchase order shall contain and define, when appropriate, penalty clauses for lack of performance and government source inspection when required.

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4. <u>Reliability and Quality Review</u>

4.1 Purchase requisitions and contracts shall be provided the Project R&QA Engineer for approval prior to release. This shall also be applicable to any Requests for Proposals.

4.2 Each submittal for procurement of material or subcontract shall be examined by the project R&QA engineer for:

4.2.1 Appropriate statement of R&QA requirements per procurement package.

4.2.2 Approved source of procurement.

4.2.3 Vendor certification of compliance.

4.2.4 Vendor inspection, data requirement and acceptance data package for suppliers of major assemblies.

4.2.5 Material analysis or certification.

4.2.6 Packaging and shipping instructions.

4.2.7 Need for special receiving and inspection requirements.

4.2.8 Drawings used for the procurement are appropriately released, approved by Documentation Control, and of the latest revision.

4.3 Approval of procurement request shall be signified by R&QA signature on each purchase order.

4.4 The project R&QA engineer shall initiate any special instructions that may be required for handling or inspection of material upon its receipt at MIT.

4.5 The project R&QA engineer shall, in the event of a determination of insufficient quality requirements, generate the necessary requirements and negotiate their inclusion in the procurement documents with the responsible project engineers.

TITLE MATERIAL PROCUREMENT, SUPPLIER AND SUB-CONTRACTOR CONTROL	NUMBER QOP 003	
	ISSUED October 1969	
	REVISED June 10, 1970	SHEET 3 OF 4

5. Vendor, Supplier or Sub-Contractor Control

5.1 The project R&QA Engineer upon initiation of any procurement shall establish and implement quality audits, quality assurance monitoring and process controls for applicable hardware.

Procurements for the Gravimeter and Surface Electrical Properties NASA Programs shall be combined wherever practical with the objective of placing a single procurement for sufficient quantities of common articles to satisfy total program needs.

5.2 The supplier control shall be based upon the complexity or criticality of the material or equipment being procured. This judgment will be made individually but the following general criteria shall apply.

5.2.1 Suppliers of parts and materials with which MIT has had previous good experience, warrant no special consideration other than verification of material characteristics upon receipt.

5.2.2 New suppliers (particularly of critical components) shall be the subject of a survey to determine acceptability of facilities and general quality practices as required.

5.2.3 Sub-contractors and suppliers of major hardware elements shall be surveyed for appropriate quality systems and practices prior to the initiation of procurement. Correction of deficiencies noted shall be negotiated and included in procurement documents. Project R&QA Engineers shall maintain a record of the results of each such survey.

5.2.4 Sub-contractors and suppliers of major hardware elements shall be the subject of periodic monitor and audit by the Project R&QA Engineer at appropriate times throughout the period of the sub-contractor or supplier's performance. Special attention shall be afforded the following areas:

5.2.4.1 Handling and accountability of materials;

5.2.4.2 Organization of and implementation of fabrication, manufacturing, and assembly operations;

5.2.4.3 Process controls and in process inspection;

5.2.4.4 Non-conforming material;

5.2.4.5 Final inspection, acceptance and test, including data package.

5.2.5 Critical parts whose quality characteristics cannot be controlled or inspected upon receipt, shall be subjected to a single procurement and source inspection performed at the time of their fabrication.

5.3 Design Review

5.3.1 The R&QA Engineer shall obtain from suppliers and sub-contractors of assemblies full disclosure of parts, materials and design of such assemblies. This disclosure shall be made at a Design Review Meeting to be held prior to the procurement of parts and materials to be used in the fabrication of the assembly.

5.3.2 The design review meeting shall be scheduled by the R&QA Engineer on a timely date that will permit parts and materials that do not meet with the R&QA Engineer's and/or NASA's approval to be changed or modified without delaying the delivery schedule of the end item hardware.

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NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE RECEIVING, INSPECTION, STOCKING, ISSUANCE AND KITTING	NUMBER QOP 004	
	ISSUED October, 1969	
	REVISED June 9, 1970	SHEET 1 OF 10

1. Purpose

1.1 It is the purpose of this procedure to:

1.1.1 Establish a system for controlling the receipt of procured parts and material.

1.1.2 Establish a system for inspection of parts and material whether procured or fabricated.

1.1.3 Define general inspection criteria.

1.1.4 Establish a stock room or stocking facility for acceptable material and raw stock.

1.1.5 Maintain a system of traceability and identification of parts and material.

1.1.6 Define the necessary records and documentation to accomplish the above objectives.

2. Scope

2.1 This procedure shall be applicable to all parts and material, procured or fabricated, destined for use in deliverable equipments.

3. Receipt of Procurred Material

3.1 All material shall be received by the Project Shipping and Receiving Group.

3.2 It shall be the responsibility of the Project Shipping and Receiving Group to:

3.2.1 Open receipts;

3.2.2 Compare shipping invoices to procurement order;

3.2.3 Check for shipping damage, proper packaging, and subsequent protection and packaging for release to stock.

3.2.4 Verify that material agrees with shipping invoice;

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3.3.5 Verify that test data, inspection data, or certificates of compliance, as required by purchase order, are included;

3.3.6 Prepare Inspection Request/Report (see Fig. 4.1)

3.3.7 Note above conditions on Inspection Request/Report;

3.3.8 Forward material received with copy of the procurement order or shipping notices and documentation received to inspection areas;

3.3.9 Assign and mark containers with lot numbers as applicable (see QOP #005.)

4. <u>MIT/DLFabricated Material</u>

4.1 All material machined or fabricated within MIT/DL shall be controlled by a Work Requisition (see Fig. 4.2).

4.1.1 The work requisition shall be initiated by Engineering and contain the following information:

4.1.1.1 Project name or number

4.1.1.2 Work requisition Serial No.

4.1.1.3 Name of originator

4.1.1.4 Description of work to be done and drawing number

4.1.1.5 Number required

4.1.1.6 Delivery requirements

4.1.1.7 Special instructions

4.1.2 The original copy of the Work Requisition shall be utilized by the shop to record information pertinent to the shop operation. In addition the shop shall record in the space provided the identification of raw material or stock used as follows:

4.1.2.1 Description;

4.1.2.2 Purchase order or inspection report number;

4.1.2.3 Lot number, if applicable.

4.2 Material fabricated at MIT/DL shall be submitted to inspection with the original of the Work Requisition and accompany the hardware to stock areas.

5. Inspection

5.1 The Inspection Areas shall establish three distinct and separate areas for the handling and storing of material as follows:

5.1.1 Receipts awaiting inspection.

5.1.2 Acceptable and inspected material for stock.

5.1.3 Unacceptable material awaiting disposition.

5.2 The Inspection Department shall accomplish the following inspections:

5.2.1 Package identification and piece part marking per drawing.

5.2.2 External visual examination for defects, i.e. scratches, burrs cracks, etc.

5.2.3 100% measurement of critical drawing dimensional characteristics per instructions of cognizant engineer or Project R&QA Engineer.

5.2.4 Functional and/or electrical measurements as defined by the drawing.

5.2.5 Other examinations as may be required by Special Instructions as prepared by Project R&QA.

5.2.6 Sample inspection shall not be employed except as specified by the drawing or special R&QA instructions.

5.3 The Inspection Department shall record the results of the above and complete the Inspection Report.

5.4 Acceptable material shall be identified and forwarded with a copy of the inspection report and other accompanying papers to the stock room.

5.5 Material that is non-conforming shall be held for resolution and disposition (see QOP 007).

5.6 Tools, gages, instruments or electrical test equipment used for inspection and measurement shall be maintained in good condition and in calibration as required (see QOP 012).

6. Inspection Report

6.1 The Inspection Request/Report shall be completed in part by the receiver and in part by the inspector as noted above and shall accompany the material.

6.2 The inspection report shall indicate the type and character of inspection work performed and clearly describe any out-of-tolerance or non-conforming condition noted.

6.2.1 If 100% of drawing characteristics are inspected it shall not be necessary to record measurements made. The statement that pieces inspected were checked 100% is sufficient. Conditions found to be non-conforming must be recorded, however, for each part with drawing tolerance and actual measurement

6.2.6 If partial inspection is accomplished, the inspection report shall clearly identify which characteristics were checked. Actual measurement data need not be recorded unless required by the drawing or special instructions unless there is a non-conformance.

6.3 All inspection reports shall be assigned a sequential serial number.

7. Material Stocking

7.1 Special Raw Material

7.1.1 Raw material and chemicals except as specified by drawing will not be inspected for composition. Vendor's certificate of compliance shall be deemed adequate. No inspection report is required unless some inspection is performed.

7.1.2 Material shall be identified upon receipt by:

7.1.2.1 Type of material;

7.1.2.2 Purchase order number;

7.1.2.3 Shipment Lot No.

7.1.3 Certificate of compliance and results of special analysis performed shall be identified by lot number of material and forwarded to the Project R&QA Engineer.

7.1.4 Raw material shall be placed in general stock by type. Identification on unissued portion of stock shall be maintained.

7.1.5 Raw material purchased specially for a particular project or part shall be identified, handled, and stocked as a part.

7.2 Parts

7.2.1 Parts deemed acceptable by reason by an inspection report or disposition of non-conformances shall be placed in project stock areas with associated documentation.

7.2.2 Parts and materials shall be identified by:

7.2.2.1 Drawing number;

7.2.2.2 Revision status;

7.2.2.3 Purchase order lot number, inspection, report, or work requisition number;

7.2.2.4 Non-conformance Report No. (if applicable).

7.2.3 After parts have been properly identified and placed in stock, associated documents shall be forwarded to the Project R&QA Engineer for filing.

7.3 Access

7.3.1 Receipt and issuance of stock shall be made only by authorized stock room personnel.

7.3.2 Access to stock areas by other than stock room personnel is prohibited.

8. Issuance of Stock

8.1 Raw Material

8.1.1 Raw material will be issued only on the presentation of an authorized Work Requisition.

8.1.2 Identification and traceability information (see paragraph 7.1.2) will be entered on the Work Requisition at the time of issuance.

8 8.2 Parts

8.2.1 Parts in stock shall be issued for assembly operations only to a kit covered by a Data Package containing the authorizing Assembly Work Order and Configuration Traceability List (CTL) (see Fig. 4.3).

8.2.2 Identification and Traceability information such as drawing number, revision letter, serial number, lot number, inspection report numbers, purchase order numbers, and MRB numbers as appropriate shall be entered on the CTL at the time of issuance.

8.2.3 Parts or assemblies in stock required for rework or retrofit shall be issued only upon presentation of an authorized Work Requisition. Traceability and Identification data shall be maintained with the article.

8.3.2 Material issued to kits for assembly operations which proves to be defective or is damaged by handling shall be removed from the kit and documented through a Material Review Action (see QOP 007). Completed MRB report shall constitute authority for issuance of replacement material from stock.

8.2.5 Documentation Control will initial each CTL released signifying verification of latest design revision status.

8.2.6 Upon kitting the stock clerk shall enter revision status of parts issued and initial CTL upon completion.

8.3 Completed Assemblies

8.3.1 Assemblies which have been completed and tested as required shall be presented for a final quality review and data package sign off.

8.3.2 Following this review, completed assemblies shall be identified with one of three tags as follows:

8.3.2.1 Red Tag - Material rejected for reason noted.

8.3.2.2 Yellow Tag - Caution, material requires additional work.

8.3.2.3 Green Tag - Material acceptable for use.

8.3.3 Completed assemblies shall be protected as appropriate and placed in bonded stores. Green tag items may be issued to the next higher assembly kits as required.

CHARLES STARK DRAPER LABORATORY

INSPECTION REPORT / REQUEST

W.O. No. 277158 B/P No. 1283760 REV. A PART NAME #IR1778 HEAT SINK, ELECT MODULE SHEET 1 OF 1

DATE REC'D 5-27-69 VENDOR Allied Research QUANTITY 8pcs. REQUESTED BY E. LaFrance PROJECT CHARGE # 55-29200-22b

INSPECTION INSTRUCTIONS

Inspect 8pcs. per 1283760.

DIMENSION	ZONE 1	2	3	4	5	8	REMARKS
1.753 +.004 -.000	1.752	1.751	1.752	1.751	1.752	1.752	
1.5780 +.004 -.000	1.574	1.573	1.574	1.573	1.577	ok	
1.403 +.004 -.000	1.398	1.398	1.397	1.397	1.402	1.402	
1.228 +.004 -.000	1.2245	1.224	1.224	1.224	1.226	1.227	
1.053 +.004 -.000	1.049	1.050	1.049	1.050	1.052	ok	
.878 +.004 -.000	.874	.876	.874	.877	.879 ok	ok	
.703 +.004 -.000	.699	.702	.700	.702	.705 ok	ok	
.528 +.004 -.000	.5254	.526	.526	.526	.531 ok	ok	
.353 +.004 -.000	.349	.352	.350	.351	.355 ok	ok	
.178 +.004 -.000	.173	.176	.175	.176	.181 ok	ok	

IAW/.005 — 1 Fin area on each pc No. 1, 2, 3, 6, and 7 are running .0108, .0085, .0075, and .0112

All dimensions conform to B/P for No. 6, and 7 also other dimensions for the above

Dimensions were taken at base of fin area

REPORT No. #A00365 STARTED 5/28/69 TIME 10:30 COMPLETED 5/29/69 TIME 9:20 INSPECTED BY [signature] INSPECTION TIME 7 PROJECT Skipper B

Fig. 4.1

WORK REQUISITION

NO. I-106

PROJECT: DSS	CHARGE: 53-27810	DATE: 5/7/69
UNIT NAME: ICAD Power Panel	NO. REQ. 1	REQ. BY 7/1/69
DWG. NO. 410-2623105 — REV B	ORIGINATOR: B. Murphy	

SPECIAL INSTRUCTIONS

Send out for anodizing upon completion of machining.

SAMPLE

ASSEMBLY S/N DSRUI

RAW MATERIAL DATA

TYPE: SS-QQ-466 LOT NO. OR PO NO. IL351066

OPERATION INSTRUCTIONS/RECORD

OPR. NO.	DESCRIPTION	COMPLETION DATE	OPERATOR OR INSPECTOR INITIALS OR STAMP
1	Draw stock and rough out	6/3	A. B.
2	Drill, Machine, and MILL	6/3	A. B.
3	Finish	6/5	A. B.
4	Inspect	6/10	E. M.
5	Anodize	6/15	T. J.

COMPLETION APPROVALS:

FOREMAN/SUPERVISOR — AREA OR SHOP — QC REPRESENTATIVE

Figure 4.2

CONFIGURATION TRACEABILITY LIST

PROJECT: OAO

ASSEMBLY NAME	DWG. NO.	REV. STATUS	DOC. CONTROL	STOCK ROOM
MA-5	1283869	E	G.S.	E.D.

PART DWG NO.	REV STATUS (DESIGN)	REV STATUS ISSUED	NO. REQ.	DESCRIPTION	P.O. or I.R. NO.	SERIAL NO.	LOT NO.	MRB NO.	REMARKS
1283887	C	C	1	Heat Sink	W05370				
1283869-1	E	E	1	Board, Left			108		
1283869-2	E	E	1	Board, Right			108		
.005x.010				Nickel wise			1		
1281568	B	B	1	Diode CR3	R13911		M3A		
1281571	E	E	2	Diode, Zener	G2712		301A		
1281550	B	B	4	Transistor Q1, Q2, Q3, Q4	R7624		1721		
1281652	B	B	1	Transistor Q7	G26113		138A		
1281597	B	B	2	Capacitor C1, C2	G35592		308A		
1281598-1	C	C	1	Capacitor, C3	G35142		109A		
1283769-100	-	-	1	Flatpack and holder	WEL004	109	152A	134	
1281587-32	D	D	5	Resistors R1, 2, 3, 4 & 8	F2677		264A	134	
1281587-11	D	D	1	Resistor, R5	F2677		264A	134	
1281590	D	D	3	Resistor R6, 7, 9	F2678		265A		
1281590	D	D	1	Resistor R10	F2678		265A		
1281695	A	A	1	Transistor Q6	F2641		152A		

Fig. 4.3

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QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 005	
SERIALIZATION AND LOT CONTROL	ISSUED October, 1969	
	REVISED	SHEET 1 OF 3

1. Purpose

1.1 It is the purpose of this procedure to provide a system for achieving traceability and identification of major hardware elements and significant component parts through serialization and lot control.

1.2 It is also the purpose of this procedure to establish criteria defining the generic types of hardware that should be serialized, lot controlled, or requiring no special attention.

1.3 It is the objective of this system to provide a vehicle for associating individual pieces or parts in a system to previous data or history on that part before it was introduced into the assembly (i.e. inspection, test or procurement records) or to trace a part or group of parts to the assembly in which they are located.

2. Scope

2.1 This procedure shall be applicable to all assemblies, components, parts, and materials selected by design engineering or the Project R&QA Engineer for serialization or lot control.

2.2 This procedure shall be applicable to such articles whether purchased or fabricated internally.

3. Serialization

3.1 The following items shall be considered for serialization:

3.1.1 Major mechanical or structural parts (i.e. gimbals, stable members, panels, etc.);

3.1.2 Major electro-mechanical devices (i.e. gyros, motors, resolvers, etc.);

3.1.3 Matched electronic components;

3.1.4 State-of-the-art or special electronic components;

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3.1.5 All major assemblies;

3.1.6 All functioning severable sub-assemblies (i.e. electronic modules, plug in units, harness or cable assemblies);

3.1.7 Any other articles or assemblies judged to be particularly significant or critical to system performance.

3.2 Serial numbers shall be affixed in a manner that does not degrade the article by the vendor (if part is procured) or by the group fabricating it. Such marking and its location should be identified on the applicable drawing and include drawing number and revision status for completeness.

3.3 Sub-assemblies or assemblies shall be assigned serial numbers at the time pieces and parts are collected or kitted prior to assembly operations. An assembly may conveniently adopt the serial number of its major structural part; i.e. the panel, housing, or case.

3.4 All serial numbers shall be recorded on the Configuration and Traceability Log (see QOP 004) at the time serialized hardware is selected or allocated for a given assembly.

3.5 Assignment of the same serial numbers to more than one assembly of like type is to be avoided. A serial number log book is suggested.

4. Lot Control

4.1 The following items shall be considered for lot control:

4.1.1 Electronic component parts (i.e., semi-conductors, resistors, capacitors, magnetic devices);

4.1.2 Connectors;

4.1.3 Meters and switches (if not serialized);

4.1.4 Chemicals susceptible to rapid deterioation or aging not otherwise controlled by process specifications.

4.2 Lot control numbers shall be assigned at the time material is received by Project Receiving Group.

4.3 The lot control number shall be composed of the MIT/DL Purchase Order Number, the P.O. line item number, and the date of receipt (i.e. 290704-3-081569) and cross referenced on the purchase order to vendor lot numbers if any present.

4.4 Lot control numbers shall be placed on the container or bag in which parts are stored and transferred to the Configuration and Traceability List at the time parts are selected or allocated to a particular assembly.

5. Uncontrolled Material

5.1 Parts and materials generally not requiring either serialization or lot control are as follows:

5.1.1 Miscellaneous hardware items (i.e. nuts, bolts, screws, clamps, etc.);

5.1.2 Paints and finishes;

5.1.3 Insulation and tubing;

5.1.4 Wire.

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QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 006	
PRODUCTION AND INSPECTION PLANNING AND CONTROL OF FABRICATED ARTICLES	ISSUED October, 1969	
	REVISED	SHEET 1 OF 8

1. Purpose

1.1 It is the purpose of this procedure to establish the planning required for Production and Inspection activities and define the system for control of the quality of fabricated articles or assemblies. It shall further be the purpose of this system to provide a documented record that:

1.1.1 Significant operations were performed, by whom, and when.

1.1.2 In process and final inspections were made, by whom, and when.

1.1.3 Tests were performed and data recorded.

1.1.4 Faults or problems occurring or discovered during the fabrication or assembly process are recorded and resolution obtained.

1.1.5 Authorized design changes as required were made.

2. Scope

2.1 This procedure shall be applicable to all fabrication and assembly operations conducted on equipments destined for delivery to the customer.

3. Purpose of Build Data Package

3.1 The Build Data Package is intended to provide:

3.1.1 The necessary instructions and documents required to complete assembly operations.

3.1.2 A permanent documented record of the manner in which an assembly was built.

4. Contents of Build Data Package

4.1 Assembly Work Order

4.2 Assembly Configuration Traceability List

4.3 Assembly Fault Log

4.4 Test Data Sheets

4.5 Drawings and specifications required for accomplishing the build.

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4.6 Special Quality Instructions, travelers, or flow charts in amplification of the Work Order as required to govern quality operations pertaining to the assembly.

4.7 Copies of ECR's incorporated.

5. Control of Build Data Package

5.1 Part kits shall not be released to manufacturing or assembly operations without an approved Build Data Package.

5.2 The Build Data Package shall remain with the hardware throughout assembly operations.

5.3 Upon completion of assembly and acceptance, the Build Data Package shall be maintained on file by project R&QA for two years unless otherwise stated in the contract requirements.

5.4 Preparation and release of the Build Data Package shall be the joint responsibility of Documentation Control Office and Project R&QA Engineer as noted below.

6. Data Package Responsibilities

6.1 Documentation Control Office

6.1.1 Serializes Assembly Work Order No.

6.1.2 Completes first portion of the Configuration Traceability List.

6.1.3 Adds copies of drawings, specifications and data sheets required for build. Also copies of ECR's that must be incorporated.

6.1.4 Approves Data Package for release to assembly operation.

6.2 Project R&QA Engineer:

6.2.1 Performs production and inspection planning incorporating results on the Work Order or by separate documents in Data Package. (See Section 8).

6.2.2 Prepares special inspection instructions as required.

6.2.3 Adds copies of Assembly Fault Log.

6.2.4 Approves Data Package for release to assembly operations.

7. Assembly Work Order (see Fig. 6.1)

7.1 The Assembly Work Order shall be initiated by the cognizant project engineer.

7.2 Parts may be issued or kitted from stock and assembly operation commenced only as authorized by the appropriate Assembly Work Order and approved Build Data Package.

7.3 The Assembly Work Order shall be placed in and remain as the first sheet of the Build Data Package.

7.4 The Assembly Work Order shall be completed per the sample (Fig. 6.1).

7.4.1 It should be noted that the initials of Documentation Control and R&QA are to indicate the Build Data Package is approved for release.

7.4.2 Production and inspection planning are to be described in sufficient detail to adequately define what is to be accomplished. In the event more detailed instructions are required, these should be prepared as separate documents, added to the data package, and referenced in the sequence of operations.

7.5 A logical first step operation would be "Kit Inspection" which implies verification that the number of proper parts are included, parts are to the latest drawing, and the CTL is complete. In addition, traceability information on parts is properly recorded.

7.6 The final step operation would be "Final Inspection" which implies verification visually of workmanship of total assembly, proper marking or serialization, and test data complete, recorded, and within specification.

7.7 Completed sub-assemblies shall be identified and placed in stock for issue to Next Higher Assembly (NHA) or moved to NHA immediately providing data is recorded in the CTL of the NHA.

8. Production and Inspection Planning

8.1 Upon receipt of the Assembly Work Order or in anticipation of subsequent assembly operations, the Project R&QA Engineer shall review applicable assembly drawings and generate the necessary production and inspection planning to:

8.1.1 Define, in sequence, significant assembly operations.

8.1.2 Establish within this sequence, meaningful inspection points.

8.1.3 Develop written criteria, if required, defining the character of the above inspection points. Special instructions will be required only when the inspection and/or test to be performed is complex and not obvious or stated in a few words.

8.2 Selection of inspection and/or test points shall generally follow:

8.2.1 Major stages of assembly operations.

8.2.2 Any operation wherein the succeeding operation will cover previous work rendering adequate inspection impossible or extremely difficult.

8.2.3 At stages of assembly operations where, if defects are located, retrofit or rework can be easily made without significant schedule or cost impact and degradation of quality.

9. Assembly Fault Log (see Fig. 6.2)

9.1 The Assembly Fault Log is the documented record of discrepant conditions noted at any stage of the assembly process or of any significant event that has occurred that might have an effect upon the quality or function of the assembly.

9.2 The Fault Log is primarily for the purpose of recording problems developed as a result of inspection or test operations but entries may be made by anyone detecting the discrepancy.

9.3 The Assembly Fault Log shall be completed when required as indicated in the sample (Fig. 6.2).

9.4 Final acceptance of an assembly shall be contingent upon the appropriate resolution and disposition of all recorded faults.

9.5 Faults may be resolved in any of the following ways:

9.5.1 MRB or waiver action,

9.5.2 ECR,

9.5.3 R&QA project engineer signoff (essentially a "no fault").

9.5.4 Rework, repair, and reinspection.

9.6 Except as mutually agreed by engineering and Project R&QA, all faults must be dispositioned before equipment proceeds to next assembly operation.

ASSEMBLY WORK ORDER

W.O. NO. 312

DHQ
(PROJECT)

PAGE 1 OF 1

ASSEMBLY WORK	DWG. NO.	BUILD TO REV.	ASSEMBLY SERIAL NO.
MA-5	1283869	E	80

SPECIAL INSTRUCTIONS:

Build to print

AUTHORIZING ENGINEER: I. Gloss

DATE: 5/21/69

BUILD DATA PACKAGE APPROVAL: DOCUMENT CONTROL: G.S.

R&QA E.L.F.

BUILD HISTORY/CHANGES INCORPORATED:

None

STEP NO.	TYPE	DESCRIPTION	PERFORMED BY	DATE
1	I	Inspect Kit	JCC	6/3
2	A	Load Module	AM	6/19
3	I	Inspect location and orientation of	J.C.C./F.W.	6/19
		components		
4	A	Weld 1st level left	A.M.	6/20
5	I	Inspect welding	J.C.C.	6/20
6	A	Bond ribbon runs	AM	6/21
7	A	Weld 1st level right	AM	6/21
8	I	Inspect welding	J.C.C.	6/21
9	A	Bond	A.M.	6/21
10	I	Inspect bonding	J.C.C.	6/21

FINAL ACCEPTANCE:

Fig. 6.1

S. Kazim (ENGINEERING)	7/10/69 (DATE)	E. La France (R&QA)	7/10/69 (DATE)

ADDENDUM SHEET

ASSEMBLY WORK ORDER

OHO (PROJECT)

W.O. NO. 312

ASSEMBLY NAME	DWG. NO.	REV.	ASSEMBLY SER. NO.
MA -5	1283869	E	80

BUILD HISTORY/CHANGE INCORPORATED:

None

STEP NO.	TYPE	DESCRIPTION	PERFORMED BY	DATE
11	A	Weld 2nd level left	A. M.	6/22
12	I	Inspect welding	J.C.C.	6/22
13	A	Weld 2nd level right	A. M.	6/22
14	I	Inspect welding	J.C.C.	6/22
15	A	Bond	A. M.	6/22
16	I	Inspect bonding	J.C.C.	6/23
17	A	Conformal Coat	R. P.	6/27
18	I	Inspect conformal coat	J.C.C.	6/27
19	T	Electrical Test	R. B.	7/2
20	A	Pot module	R. P.	7/6
21	T	Final Electrical Test	R. B.	7/7
22	I	Inspecting potting, verify	J.C.C.	7/7
		calibration status of list equip.		
		Verify completions of list data		
		Fig. 6.1a		

ASSEMBLY FAULT LOG

PROJECT: OHO

ASSEMBLY DWGN. 1283868 SER. NO. MA582

NO.	DATE	DESCRIPTION	ORIGINATOR	DISPOSITION: MRB NO.	ECR NO.	REWORK & REINSPECTION	REMARKS
1.	8/869	CR2 weld bad-reworked and welded on lower lead	J.C.C.			J.C.C.	
2.	8/9/69	Q1 Pin one-bad weld-ribbon cut and rewelded higher	J.C.C.			J.C.C.	
3.	8/9/69	Ribbon welded on wrong side of CR4	J.C.C.				Use as is
							E. L. F.
4.	8/9/69	Ribbon cut too short-new ribbon rewelded between P3 and Q2	J.C.C.			J.C.C.	
5.	8/11/69	Potted module oversize in length by .020	J.C.C.	135			

Fig. 6.2

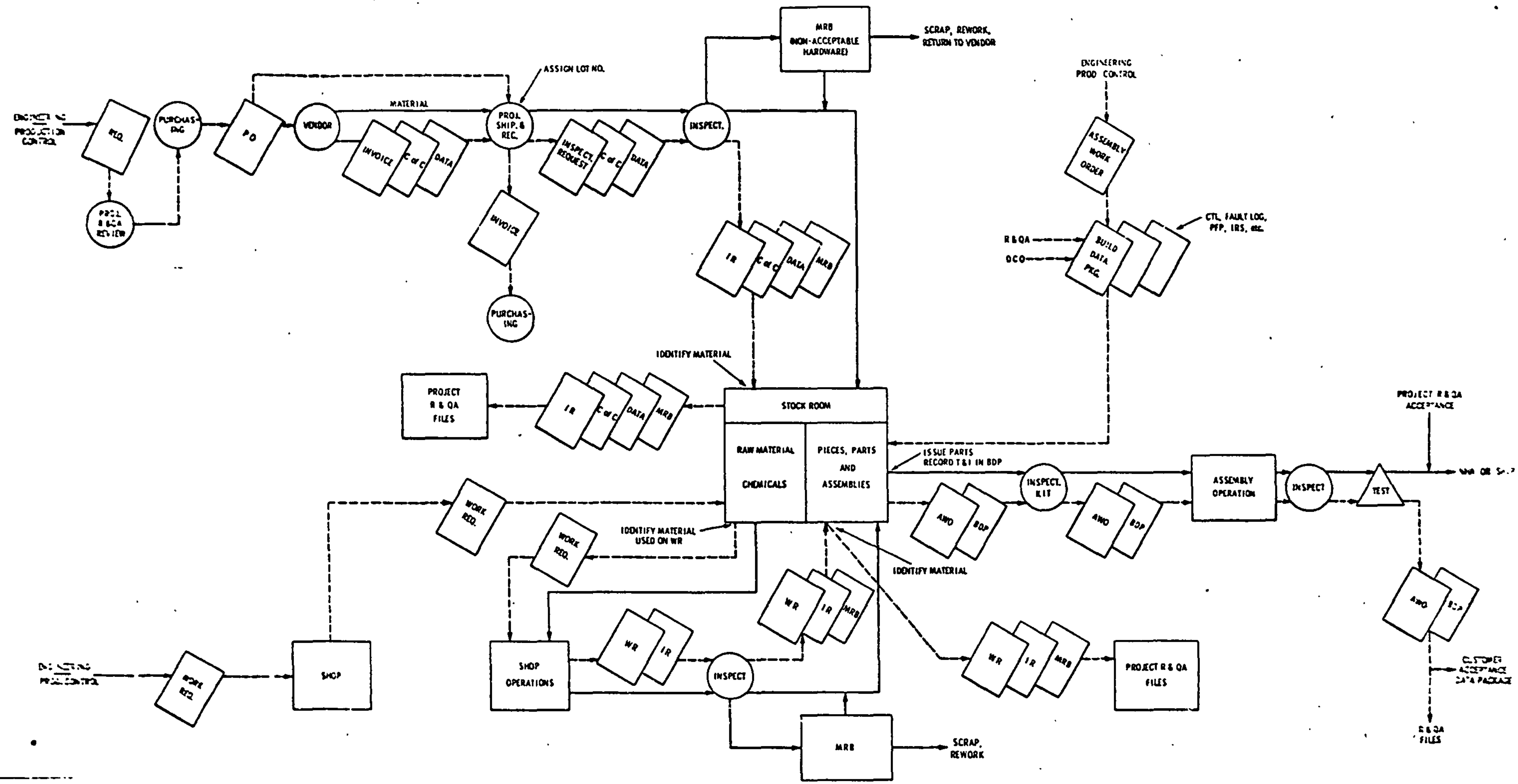

Fig. 6.3

Normal Flow of Material and Documentation

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 007	
NON-CONFORMING MATERIAL/WAIVERS	ISSUED October, 1969	
	REVISED	SHEET 1 OF 6

1. Purpose

1.1 It is the purpose of this procedure to establish and define the system for controlling and dispositioning of material classified as non-conforming or deviating from drawing, specification, or contract requirements.

1.2 To provide for the implementation of corrective action which will prevent reoccurence of the problem.

2. Scope

2.1 This procedure shall be applicable to all material purchased, fabricated, assembled, or tested within the Project and which is destined for delivery to the customer.

2.2 A non-conformance for the purpose of this procedure is defined as any deviation, discrepancy, or unusual condition detected or anticipated to end item equipments or parts thereof.

2.3 All non-conformance shall be processed by the Material Review Board in accordance with this procedure.

3. Material Review Board

3.1 The Material Review Board shall consist of the following indifiduals:

3.1.1 R&QA - Chairman;
3.1.2 Project Engineering;
3.1.3 Manufacturing (only to assist in rework dispositions);
3.1.4 Resident Government Inspector, (ONR)

3.2 The MRB shall meet as a group whenever practical though such is not a requirement to performing its function.

3.3 The MRB may disposition material as:

3.3.1 Scrap
3.3.2 Rework or repair to print
3.3.3 Use as is

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3.4 A disposition of "Rework" or "Scrap" may be made by the chairman and need not be presented to other members except as for information.

3.5 A disposition of "Use as is" must receive the unanimous concurrance of all members and signature approval.

3.6 Non-conformances dispositioned "use as is" that affect end item characteristics as follows, shall be designated as waivers, so stamped, and further processed:

- 3.6.1 Interchangeability;
- 3.6.2 Form or Fit;
- 3.6.3 Function or Performance;
- 3.6.4 Life or Reliability;
- 3.6.5 Contracts

3.7 The MRB report shall be used for recording and processing waiver actions.

3.8 Concurrance for all waiver actions shall be obtained from the resident NASA technical representative. If in his judgment the waiver action affects costs, schedule, or contracts, then the concurrance of the NASA Contracting Officer shall be obtained.

3.9 Use of or continuation of hardware pending waiver action in fabrication or assembly operations requires project management approval.

4. <u>The MRB Chairman</u>

4.1 Organizes and chairs meetings.

4.2 Presents material for consideration. (Includes physical piece, drawings, and other documents as applicable.)

4.3 Prepares MRB reports and obtains member action as required.

4.4 Maintains MRB records.

4.5 Establishes custody and control over material awaiting disposition and that of dispositioned as scrap.

4.6 Obtains customer approval of waiver actions. (See 6.2).

4.7 Initiates corrective action and follows up to assure effective and timely implementation.

5. MRB Material Control

5.1 Material designated as non-conforming and awaiting MRB action shall be positively identified by a "Reject Tag" (Fig. 7-1) which clearly describes the nature of the non-conformance and the originator's name.

5.2 Material will normally be designated as non-conforming by quality or inspection personnel but action may be initiated by anyone detecting the discrepancy.

5.3 Material so designated shall be segregated or removed from the normal flow of acceptable material or otherwise placed in the custody of Project R&QA for MRB disposition.

5.4 Reject tags may be removed from material and the material returned to the normal flow only by the Project R&QA Engineer and then only after completed MRB action.

5.4.1 Material in stock with history of discrepancy shall be identified by applicable MRB number.

5.4.2 Material in assembly operations shall be identified in the Data Package with the applicable MRB number.

5.4.3 A completed MRB action shall be sufficient justification to cause "buy off" of outstanding fault logged against any assembly in process in the Assembly Fault Log. (See QOP 006 and 008.)

6. MRB Reports and Log

6.1 MRB or waiver activity shall be documented on the MRB Report Form. (See Fig. 7.2).

6.2 The MRB report shall be completed as shown in the example.

6.3 MRB reports shall be distributed as follows:

6.3.1 Original - Quality files

6.3.2 Copy - accompanies material - placed in data package when material is consumed in assembly.

6.3.3 Copy - Customer information copy only as required by contract or if reporting waiver action.

6.3.4 Copy - Government Inspection Agency information if required.

6.4 The Project R&QA Engineer shall maintain an MRB Status Log which contains the following data:

6.4.1 MRB No. and Project Name

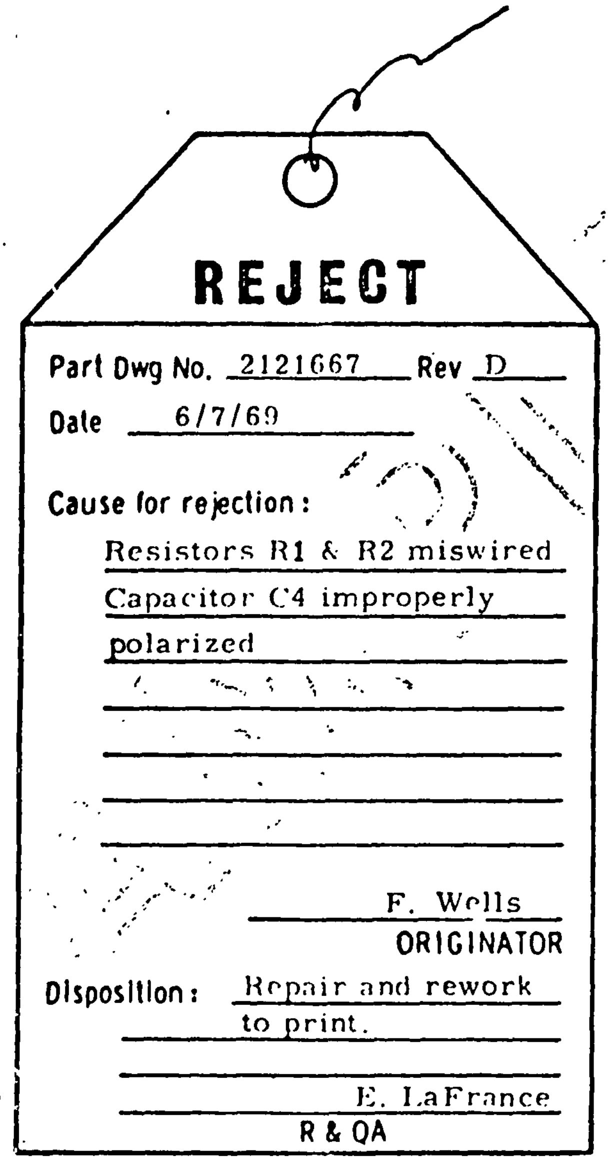
6.4.2 Date

6.4.3 Drawing number of affected material

6.4.4 Description of non-conformance (i.e. dimension out-of-spec, workmanship, test)

6.4.5 Disposition (S - Scrap, R - Rework, U - Use as is)

6.4.6 Corrective Action Status (P - Pending, C - Complete)



REJECT

Part Dwg No. 2121667 Rev D

Date 6/7/69

Cause for rejection:

Resistors R1 & R2 miswired
Capacitor C4 improperly
polarized

F. Wells
ORIGINATOR

Disposition: Repair and rework
to print.

E. LaFrance
R & QA

(THIS TAG IS RED)

Fig. 7.1

______________ (PROJECT)

CHARLES STARK DRAPER LABORATORY

M. R. NO. ______

DATE 8/1/69

Sheet 1 of 1

MATERIAL REVIEW ACTION REPORT

DWG. NO. 1283871 REV. C TITLE MIII Module Serial No. 82

SOURCE MIT P. O. NO. NA QTY. REC. NA

IR NO. 1917 S/N or LAB NO. NA ACCEPT NA

DEFECT NO.	SPEC. REQUIREMENT	DESCRIPTION OF DEFECT OR NONCONFORMANCE	QUANTITY INSP.	QUANTITY DEF.	USE AS IS	REPAIR	SCRAP	RETURN TO VENDOR		WAIVER
1.	.040 Dim. at zone D - 6	Measures .030	1	1	x					
2.	Case to ground insulation resistance greater than 50 meg ohm	Measures 35 meg ohms	1	1	x					

SAMPLE

CORRECTIVE ACTION:

1. New fixture developed to prevent module misalignments
2. None

REASON FOR ACCEPTANCE OR WAIVER:

1. .030 is more than adequate to prevent adverse conditions of form and file.
2. Will not affect function.

MRB CONCURRENCE

E. La France — R&QA

S. Kazim — ENGINEERING

W. Moore (opr) — GOVT. INSP.

WAIVER CONCURRENCE

NASA Contracting Officer (as required) ______ Date ______ NASA Tech. Officer ______ DATE ______

Fig. 7.2

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NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE		
IN PROCESS INSPECTION AND TEST	NUMBER QOP 008	
	ISSUED October 1969	
	REVISED May 13, 1970	SHEET 1 OF 3

1. Purpose

1.1 It is the purpose of this procedure to establish and define the responsibilities of the Project R&QA Engineer and Inspection personnel relative to In Process Inspection of Assembly and Test Operations. As important as it may be to perform inspection on completed hardware to assure a quality output, it is equally important to monitor the processes and techniques being employed in order to protect against the defect being generated. and by proper inspection provide for early defect detection at lowest level of assembly.

2. Scope

2.1 This procedure shall be applicable to assembly and fabrication operations performed on articles destined for delivery.

3. Personnel Techniques

3.1 Personnel techniques are those functions related to individuals wherein quality is dependent to a large extent upon the skill, training, or experience of the operator (i.e. soldering, wiring, harnessing).

3.2 The Project R&QA Engineer and inspection personnel shall monitor on a periodic basis and observe such operations.

3.3 Every effort shall be made to correct bad practices conducive to poor quality by bringing such to the attention of the individual operator and providing instruction on proper techniques. Continued bad practice shall be reported to supervisory personnel.

3.4 The Project R&QA Engineer shall review personnel techniques required of a particular project and generate specifications governing the technique and criteria of inspection as deemed necessary. Such specifications will not be released as a part of the design documentation but shall be subject to an internal change control system maintained by the R&QA project engineer. Each such procedure shall be coordinated with cognizant design and manufacturing groups.

R&QA APPROVAL [illegible signature] DATE 6/9/70

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE		
IN PROCESS INSPECTION AND TEST	NUMBER QOP 008	
	ISSUED October 1969	
	REVISED May 13, 1970	SHEET 2 OF 3

4. Process Controls

4.1 Certain operations involve equipment or machine parameters and characteristics which must be maintained within tolerances in order for the process to produce the desired results. (i.e. resistance welding, encapsulation).

4.2 The Project R&QA Engineer shall review all special processes required for a particular product and generate specifications for the control and assessment of the processes as may be applicable.

4.3 The above specification shall prescribe the degree of monitoring of these processes by quality personnel and the frequency thereof.

5. Test

5.1 Sub-Assembly or assembly test shall be monitored by the quality personnel as specified in the Production and Inspection Planning.

5.2 In addition the Project R&QA Engineer shall review all final acceptance test specifications for articles delivered to the customer and define the degree of mandatory inspection required during the test.

5.3 Quality personnel witnessing or monitoring test operations shall:

5.3.1 Verify valid test equipment calibration;

5.3.2 Assure compliance to test procedures;

5.3.3 Assure test equipment or test operators do not engage in practices which may be harmful or do damage under test;

5.3.4 Verify completeness and proper record maintenance of test data.

6. Discrepant Conditions

6.1 Practices or defects produced in the hardware shall be documented in the Assembly Fault Log.

6.2 Malpractice or improper techniques shall be the subject of immediate corrective action.

TITLE IN PROCESS INSPECTION AND TEST	NUMBER QOP 008	
	ISSUED October 1969	
	REVISED May 13, 1970	SHEET 3 OF 3

7.0 Government Source Inspection

7.1 The NASA experiment hardware destined for delivery will be subjected to Government Source Inspection by representatives of the Office of Naval Research (ONR).

7.2 The project R&QA engineer shall maintain liaison with ONR and assist in the establishment of mandatory ONR inspection points.

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS

QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 009	
ELECTRICAL TEST & FINAL ACCEPTANCE	ISSUED October, 1969	
	REVISED	SHEET 1 OF 2

1. Purpose

1.1 It is the purpose of this procedure to define quality activities during electrical and/or functional test operations.

2. Scope

2.1 This procedure shall be applicable to all such tests on completed sub-assemblies, assemblies, and the end item destined for delivery to the customer.

3. Planning

3.1 Electrical and Performance type testing is governed by ATP/S which define test procedures, sequence, characteristics to be measured, and data to be recorded.

3.2 The Project R&QA Engineer will review each ATP/S and establish mandatory inspection points as required. In the event the tests are extremely complex, a Quality Inspection Plan and sign off sheet shall be generated.

4. Engineering Responsibilities

4.1 Notify Project R&QA Engineer reasonably in advance of time test is to be initiated.

4.2 Conduct test.

4.3 Record Test Data and significant events occurring during test.

4.4 Report failures.

5. Project R&QA Responsibilities

5.1 Inspect test area and setup prior to initiation of each test.

5.2 Assure test equipment is within calibration and properly functioning.

5.3 Perform periodic monitoring of test operations.

5.4 Review completed test results and data sheets for conformance to specifications and completeness.

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TITLE	NUMBER QOP 009	
ELECTRICAL TEST & FINAL ACCEPTANCE	ISSUED October, 1969	
	REVISED June 9, 1970	SHEET 2 OF 2

5.5 Sign off QC acceptance of assembly.

5.6 Abnormalities or problems noted shall be recorded on the Assembly Fault Log and dispositioned in the normal fashion.

6.0 Final Acceptance Test Equipment Certification

6.1 The Project R&QA engineer shall provide certification that all final acceptance test equipment is within current calibration utilizing standards traceable to the National Bureau of Standards pursuant to QOP 012.

CHARLES STARK DRAPER LABORATORY
NASA LUNAR EXPERIMENTS
QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 010	
ACCEPTANCE DATA PACKAGE	ISSUED October, 1969	
	REVISED June 9, 1970	SHEET 1 OF 3

1. Purpose

1.1 The purpose of this procedure is to define the contents of the Data Package that will be prepared upon delivery and acceptance of end item hardware destined for flight or qualification test and deliverable Ground Support Equipment.by the customer. All or part of this Data Package may be provided the customer depending upon his requirements.

2. Scope

2.1 This procedure is applicable to all hardware elements, assemblies, or systems delivered as an end item to the sponsor.

3. Contents

3.1 The Acceptance Data Package shall be an accumulation of documents and data derived during the build and test cycle of each item of hardware and its major assemblies which will define the quality level of that hardware and which will assist the customer to make effective use of it. The Data Package will include the following information unless otherwise directed by applicable contract:

3.1.1 Record of "As Built" Configuration;
3.1.2 Record of Non-Conforming items;
3.1.3 Record of Failure History;
3.1.4 Operating History;
3.1.5 Acceptance or Performance Test Data;
3.1.6 Acceptance Sign Off Sheet.

3.2 The acceptance data package pertaining to deliverable prototypes may be limited to items 3.1.1 and 3.1.5 above as appropriate.

4. "As Built" Configuration

4.1 The "As Built" configuration shall be a listing of the major sub-assemblies and assemblies comprising the end item by:

4.1.1 Drawing Number;
4.1.2 Rev. Status to which built;

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4.1.3 Name of assembly;

4.1.4 Serial No. if applicable and location.

4.2 This listing may be specially compiled or merely the assumulation of the applicable CTL's.

4.3 This listing shall at a minimum describe assemblies down to the levels of serviceability or field maintenance.

5. Record of Non-Conformance

5.1 The record of non-conformance shall be a tabulation of the MRB and waiver action against levels of hardware contained in the "AS Built" configuration record showing:

5.1.1 MRB or Waiver No.;

5.1.2 Date;

5.1.3 Assembly and assembly serial number to which applicable;

5.1.4 Brief statement of non-conformance and comment on effect.

5.2 In the event the accumulated CTL's are used; the reference to MRB's thereon shall be considered sufficient.

5.3 Copies of the applicable MRB's will be included in the ADP only upon customer request.

6. Record of Failures

6.1 A summary of failures that have been logged against an end item from the time of final acceptance test to delivery.

6.2 This summary of failures shall include the following information:

6.2.1 Failure Report No.;

6.2.2 Date;

6.2.3 Identity of failed piece, i.e. Drawing Number, name, etc.;

6.2.4 Description and cause of failure;

6.2.5 Disposition and corrective action taken.

6.3 Copies of failure reports shall not be included in the ADP except as may be expressly requested by the customer.

TITLE	NUMBER QOP 010	
ACCEPTANCE DATA PACKAGE	ISSUED October, 1969	
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7. Operating History

7.1 A chronological record of events occurring and operating time accumulated on deliverable end items from the commencement of final acceptance testing to time of delivery.

8. Acceptance or Performance Test Data

8.1 A compilation of all completed test data sheets reflecting performance parameters demonstrating contract compliance or vital to proper use and assessment of the end item acquired from the time of final acceptance test to the time of delivery.

8.2 Test data on functionable severable assemblies/or field maintenance hardware levels not included or measured during end item acceptance tests and indicative of their proper performance shall also be included.

9. Acceptance Sign Off

9.1 Each Data Package shall contain a single front sheet or title page which identifies the end item and contains provision for the signature approval of its acceptance by the responsible project design engineer and the Project R&QA Engineer.

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QUALITY OPERATING PROCEDURE

TITLE HANDLING OF GOVERNMENT FURNISHED EQUIPMENT	NUMBER QOP 014	
	ISSUED 12-10-69	
	REVISED June 9, 1970	SHEET 1 OF 2

1. Purpose

1.1 It is the purpose of this procedure to provide a method for the proper handling/storage of Government Furnished Equipment and notification to the Government of discrepant or failed articles.

2. Scope

2.1 This procedure shall be applicable to all Government Furnished Equipment intended for use as part of the deliverable hardware of the NASA Experiment Programs for the time of its receipt until control is again relinquished to the government.

3. Receipt of Equipment

3.1 Upon receipt of GFE, the recipient shall notify the government inspection agency (ONR), the resident NASA technical representative, and the project R&QA engineer.

3.2 The Project Quality Engineer and the resident government inspector (at his discretion) shall examine the GFE for:

3.2.1 Shipping container damage and shipping damage to equipment.

3.2.2 Presence of required documentation and data.

3.2.3 Perform visual mechanical inspection.

3.2.4 Perform or cause to be performed a functional test at the earliest opportunity.

3.3 Discrepancies noted during the above examination shall be reported on the appropriate government form.

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TITLE HANDLING OF GOVERNMENT FURNISHED EQUIPMENT	NUMBER QOP 014		
	ISSUED 12-10-69		
	REVISED May 13, 1970	SHEET 2 OF 2	

3.4 The above form shall be used as official notification to the government of discrepant conditions existing with GFE.
Copies of the form shall be distributed as follows:

3.4.1 Government Representative
3.4.2 Project Manager
3.4.3 Project Quality Engineer
3.4.4 Cognizant Engineering Group

3.5 Each discrepancy report generated will be handled for resolution and corrective action by the Corrective Action Committee (See QOP #011) except that government concurrence is required of action recommended or taken.

3.6 Discrepant GFE hardware shall be so identified and placed in Bonded Stores pending resolution.

4. Acceptable GFE

4.1 Acceptable GFE shall be repacked for protection and placed in bonded stores pending use or delivery.

4.2 A Unit Log Book shall be established on each item of GFE in which a record shall be maintained of its status, operational and test history, and discrepancy reports.

4.3 The first entry in this log book shall note the date of receipt, results of incoming examination, and the date item was placed in bonded stores.

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QUALITY OPERATING PROCEDURE

TITLE		
CALIBRATION AND STANDARDS	NUMBER QOP 012	
	ISSUED October, 1969	
	REVISED	SHEET 1 OF 4

1. Purpose

1.1 It is the purpose of this procedure to establish and implement a system for assuring that test equipment and instruments used for measurements are within accuracy specifications and calibrated at periodic intervals against standards traceable to the National Bureau of Standards.

2. Scope

2.1 This procedure shall be applicable to all such equipment within the project and to other equipment within the MIT/DL which is utilized on the project for measurement.

3. Responsibility

3.1 It shall be the responsibility of the Project R&QA Engineer to establish and maintain the system of calibration within the project and to provide the necessary liasion with the MIT Calibration & Standards Laboratory (CSL) to assure effective implementation.

4. Equipment Inventory Control

4.1 At least once a year, an inventory of all test equipment and measuring instruments will be conducted by the Project R&QA Engineer.

4.2 The results of this inventory shall be used to establish and update the Inventory/Calibration History Cards (see Fig. 12.1) maintained by the CSL. These cards, prepared in duplicate, will be contained in two files.

4.2.1 Inventory File - Alphabetically by type of equipment.

4.2.2 Calibration File - By month in which next calibration or check is due.

4.3 The Inventory/Calibration History Cards shall contain the following information:

4.3.1 Instrument Description

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4.3.2 Manufacturer

4.3.3 Manufacturer Model Number

4.3.4 Serial and property number

4.3.5 Date acquired or first inventoried

4.3.6 Type check required

4.3.7 Date calibrated

4.3.8 Summary of work accomplished

4.3.9 Date next calibration due.

4.3.10 Activity to which instrument is assigned

4.3.11 Identification of personnel performing calibration.

4.4 Instrument Usage - All instruments used in the project will be divided into three categories and will be identified by the type of sticker affixed to the front panel of the instrument.

4.4.1 Calibrated - Instruments that are used for absolute measurements will be periodically checked to assure specification accuracy for all characteristics. The sticker shown in Fig. 12.2 will give the last calibration date and also specify the due date for the next calibration.

4.4.2 Limited Use - Equipment used for absolute measurement accuracy has been verified for only those characteristics listed (See Fig. 12.3).

4.4.3 Calibration Not Required - Instruments not used for absolute measurement but for indication only, or instruments which by their nature must be assessed for accuracy and set up each time used will be identified by the sticker shown in Fig. 12.4. The Project R&QA Engineer must approve issuance of each such sticker.

5. <u>Calibration</u>

5.1 Calibration shall be performed by CSL personnel using standards traceable to the Bureau of Standards or by outside contract sources having such capabilities.

5.2 The Standards Laboratory Instruction Manual (SLIM) shall be used as a guide in conducting the calibration program.

5.3 The CSL will establish the frequency required for instrument recalibration and recall.

5.4 The CSL will review the Calibration File monthly and advise by written notice to the Project R&QA Engineer and cognizant project personnel of the instruments that will require calibration within that month.

5.5 It shall be the responsibility of cognizant project personnel to make arrangements with the CSL for the calibration of the instruments upon receipt of the recall notice and prepare for pickup of the equipment by CSL for calibration.

5.6 Instruments not received in response to the recall notice or past calibration due dates shall be conspicuously labelled by the CSL or Project R&QA with a red reject sticker.

5.7 Cognizant personnel shall be advised of the condition of any instrument submitted for calibration and found to be significantly out of calibration or adjustment. The Project R&QA Engineer shall assess the impact of this condition on the hardware or tests that may have been processed with this equipment.

INSTRUMENT	MANUFACTURER	MODEL	SERIAL NO
VOLTMETER	HEWLETT PACKARD (HEA)	23440A	s637-06194

INDICATING INST - FS RANGE	ACTIVITY INSTRUMENT ASSIGNED TO	PROPERTY NO
	IL5-111 Wiggins FBM "A"	53-284-7

DATE CALIBRATED	TAG NO	CALIBRATING TECHNICIAN	NEXT CALIBRATION DUE	REMARKS ILG246798
12-21-6	11208	HE	1-21-7	INCOMING INSPECTION CAL
3-6-7	11921	HE	4-6-7	CAL
1-13-7	13119	HE	5-13-7	CAL
5-17-7	13732	HE	6-17-7	CAL
12-15-7	18555	HE	1-15-8	CAL
1-29-8	18623	HE	3-29-8	RESEAT PWR SUPPLY AND CAL
3-1-8	19983	HE	3-29-8	REPL. Q1-35V SUPPLY AND OP. CHK.
4-11-8	14740	HE	5-11-8	CAL
6-24-8	21875	HE	9-24-8	CAL
10-2-8	23868	HE	1-2-9	CAL
1-21-9	25289	HE	4-2-9	CAL
5-7-9	27995	HE	8-7-9	CAL

TEST INSTRUMENT CALIBRATION RECORD (CSL-MIT-IL) TPP6719

Fig. 12.1

CSL - MIT - IL
CALIBRATION
DUE 1-17-69

Fig. 12.2

CSL - MIT - IL
LIMITED USE
Calo to 100 KHz
CHARACT. VERIFIED
DUE 2-15-70

Fig. 12.3

NOT USED FOR MEASUREMENT
NO CALIBRATION REQUIRED
SSL-MIT-IL BY 10-10-68

Fig. 12.4

TITLE		
FAILURE REPORTING AND CORRECTIVE ACTION	NUMBER QOP 011	
	ISSUED October, 1969	
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4.5 The Failure Report/Corrective Action Form shall be completed as shown on the example (Fig. 11.1).

4.5.1 The discription of the problem should be as complete as possible. Include all symptons and circumstances surrounding the failure.

4.5.2 A report of any analysis of diagnostic effort undertaken to idetify the probable or actual cause of failure must be included.

4.5.3 The report shall include any action taken to correct the problem and to preclude it from reoccurring on this or future assemblies. Disposition of the failed part should be indicated.

5. Corrective Action Committee

5.1 The Corrective Action Committee shall be comprised of the following representatives:

5.1.1 Design Engineer

5.1.2 Fabrication Group Leader

5.1.3 Project R&QA Engineer

5.2 Each failure report shall be reviewed at periodically scheduled meetings by the Corrective Action Committee for completeness, adequacy of failure analysis and effectiveness of corrective action.

5.3 The Project R&QA Engineer shall sign off each failure report when action taken is deemed sufficient. All reports will be considered open until such sign off.

6. Reporting

6.1 The Project R&QA Engineer shall maintain a Failure & Corrective Action File containing the following information:

6.1.1 Failure and Corrective Action Reports;

6.1.2 Additional information and data generated in support of the failure analysis and evaluation of corrective action.

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QUALITY OPERATING PROCEDURE

TITLE	NUMBER QOP 011	
FAILURE REPORTING AND CORRECTIVE ACTION	ISSUED October, 1969	
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6.2 The Project R&QA Engineer shall at periodic intervals provide a summary to project management of all failures which have occurred. Failures remaining open shall be identified and comment included as to effort outstanding.

6.3 The Project R&QA Engineer is charged with the responsibility for:

6.3.1 Maintaining and updating failure reports;

6.3.2 Coordinating and assuring timely action of events in failure - failure analysis - corrective action cycle;

6.3.3 Determining effectiveness of corrective action;

6.3.4 Scheduling corrective action meetings;

6.3.5 Analysis of accumulated failure reports for trends or reoccurring problems;

6.3.6 Obtaining vendor or supplier failure analysis and corrective action.

6.3.7 Distribution of copies of failure reports and analysis on all failure events occurring at final acceptance test and subsequent to ROMIT, MSC, and ONR.

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QUALITY OPERATING PROCEDURE

TITLE	
QUALIFICATION AND SPECIAL TESTING	NUMBER QOP 016
	ISSUED May 15, 1970
	REVISED — SHEET 1 OF 4

1. Purpose

1.1 It is the purpose of this procedure to establish the basic requirements for control, review and documentation of any qualification and special testing activities.

2. Scope

2.1 This procedure shall be applicable to the testing of experiment hardware designated as the qualification model and any assemblies thereof.

2.2 This procedure shall be applicable to any special environmental testing of prototype experiment hardware.

2.3 This procedure is also applicable to any special evaluation testing performed on parts, materials, or sub-assemblies within experiment hardware.

3. Qualification Testing

3.1 It is planned to conduct formal qualification tests on one complete set of hardware for each experiment.

3.2 Thirty (30) days prior to the planned start of test, or as required by contract, the responsible engineering shall submit to the Test Review Board (See paragraph 6.0) for review and approval, the qualification test plan and procedure. These plans shall contain at a minimum the following information.

3.2.1 Objectives of the test.

3.2.2 Definition of hardware to be tested and its configuration.

3.2.3 Test equipment set up and description.

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3.2.4 Definition of test conditions (environments), operating modes and test method.

3.2.5 Data measurements required and data sheets

3.2.6 Accept/reject criteria

3.2.7 Schedule

3.3 Thirty (30) days following completion of the test, a formal report shall be submitted to the Test Review Board for review and approval. It shall contain the following data.

3.3.1 Reference to Test Plan

3.3.2 Deviations from plan occurring in the testing

3.3.3 Photographs as applicable

3.3.4 Test results and operating log

3.3.5 Test data and analysis

3.3.6 Conclusions

4. <u>Special Testing</u>

4.1 It is planned to conduct engineering tests and special field tests on prototype experiment hardware.

4.2 The plan for such testing shall be documented in memorandum form generally describing the effort and what is to be accomplished. This plan shall be submitted to the Test Review Board for review prior to initiation of the tests.

4.3 Upon completion of the tests or periodically during their conduct as appropriate, a memorandum report describing the tests conducted and results obtained shall be prepared and submitted to the Test Review Board for review.

5. Evaluation Testing

5.1 It is planned to conduct such evaluation tests on parts, materials, and sub assemblies to assess their suitability for application in flight hardware.

5.2 Cognizant engineers shall advise the test review board of such tests.

5.3 Results of evaluation tests shall be documented in memorandum reports and submitted to the Test Review Board for review.

6. Test Review Board (TRB)

6.1 The TRB shall be comprised of the following personnel:

6.1.1 Project Technical Director (Chairman)
6.1.2 Cognizant Design Engineer
6.1.3 Project R&QA engineer (Recorder)
6.1.4 Local NASA representative as desired

6.2 The TRB shall meet periodically as required but no less frequently than once a month.

6.3 The TRB shall function as follows:

6.3.1 Review and approve Qualification Test Plans and Reports.

6.3.2 Review Special and Evaluation Test Plans

6.3.3 Monitor progress of all tests and maintain status.

6.3.4 Retain test documentation.

6.3.5 Review all test failures, test problems, and changes providing decision and direction for retest or alteration.

6.3.6 Report to NASA upon the flight qualification and worthiness of flight hardware delivered.

7. Failures

7.1 Failures occurring during the test activities shall be reported as defined in QOP 011.

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QUALITY OPERATING PROCEDURE

TITLE PERSONNEL TRAINING AND CERTIFICATION	NUMBER QOP 017	
	ISSUED May 15, 1970	
	REVISED	SHEET 1 OF 2

1. Purpose

1.1 It is the purpose of this procedure to establish the basic requirements for the training and certification of personnel operating on deliverable hardware.

2. Scope

2.1 This procedure shall be applicable to personnel involved in the fabrication and assembly of hardware requiring special techniques and processing.

2.2 This procedure is applicable to such operations as soldering, resistance welding, parallel gap soldering, etc.

3. Training Requirements

3.1 The project R&QA engineer shall in his review of hardware designs, production and inspection planning as required by QOP's 002 and 006 define the special techniques which will require trained personnel.

3.2 The Project R&QA engineer shall establish the level of training required and criteria for certification.

3.3 The project R&QA engineer shall arrange special courses or schools as may be necessary and record completion in the appropriate personnel files.

3.4 Personnel not adequately trained or certified shall not be allowed to perform the above defined operations.

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4. Maintenance of Certification

4.1 The Project R&QA engineer shall monitor the performance of trained operators.

4.2 Excessive workmanship faults shall be cause for removal of personnel from the operation until recertified by the Project R&QA engineer.

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QUALITY OPERATING PROCEDURE

TITLE FAILURE MODES AND EFFECTS ANALYSIS	NUMBER QOP 018	
	ISSUED May 15, 1970	
	REVISED	SHEET 1 OF 3

1. Purpose

1.1 It is the purpose of this activity to define as early in the design phase but no later than design release to production, the Failure Modes of experiment hardware, to establish the effects of such failures upon the proper function of the hardware, to determine the effect of such failures upon other spacecraft systems or its crew, and to cause early modification of design to afford maximum protection against effects judged detrimental to crew safety or mission success.

2. Scope

2.1 This procedure shall be applicable to each major functional assembly level.

3. Failure Modes

3.1 The cognizant design engineer and the Project R&QA engineer shall jointly review each functional assembly and document the manner in which each may fail either catastrophically or degrade sufficiently to impair performance.

3.2 The probable cause either internal or external to the assembly will be established.

3.3 Themethod for crew detection of each failure mode will be defined.

4. Effects Analysis

4.1 Each failure mode identified shall be studied for its effect upon:

4.1.1 Crew safety

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4.1.2 Other spacecraft systems

4.1.3 Successful accomplishment of experiment mission.

5. Correction

5.1 Measures takenor recommended to correct or protect against such failure modes will be defined.

6. Reporting

6.1 The results of the analysis on each assembly will be documented on the FMEA format.(See Figure 18.1)

6.2 Upon completion of the study, the FMEA forms will be compiled and a report summarizing the conclusions prepared.

Failure Modes and Effects

SAMPLE

Name of Assembly 3200 CPS

Function: Stabilization Power Supply

Drawing Number 201006

Designer: M. Kramer

5. Failure Modes and Effects

Modes	Probable Cause		Effect	Detection Method	Design Action
A. No Output	Multivibrator: AAC & Filter: Amplifier:	No Output No Output No Output	Loss of platform stabilization - ISS out of commi-ssion.	Alarm Light; ISS fail light.	1. Select circuit configuration that imposes minimum stress on components.
B. Low Output with High Frequency Oscillation	Amplifier:	Oscillates	Degradation of inertial component performance - Change in PIPA moding.	Bias Tests.	2. Design ample margins (thermal, mechanical, (electrical stress)
C. Low Output with Severe Distortion	Amplifier:	Half-Open	Same as B	Same as B	3. Test to determine that module margins are adequate at system integration.
D. Low Output and Severe Distortion a High Erratic Frequency	Multivibrator:	Unbalanced and Erratic	Loss of inertial component suspension. Loss of stabilization loop gain. Change in PIPA moding	Bias Test Unusual Error Signals	
E. Wrong Frequency	Multivibrator	Frequency establishing components degrade.	Degradation of suspension stiffness. Random errors in stab and PIPA loops.	Same as D	

Figure 18.1

APPENDIX 6.4

PROCUREMENT SPECIFICATION FOR THE

DATA STORAGE ELECTRONICS ASSEMBLY

Specification No. 2024700
Revision No. ______
Release Date ______
Page I-1

PROCUREMENT SPECIFICATION

DATA STORAGE ELECTRONIC ASSEMBLY

Number 2024700

LUNAR SURFACE ELECTRICAL PROPERTIES EXPERIMENT

DATE	REVISION LETTER	TDRR NO.	PAGES REVISED	APPROVALS	
				MIT	NASA

This specification consists of Pages 1 to 10 inclusive.

APPROVALS

NASA/FOLE	NASA/MSC	MIT/CSR	______

CONTENTS

1. SCOPE

1.1 General

This specification establishes design, fabrication, performance, quality assurance and preparation for delivery of the Data Storage Electronics Assembly (DSEA) to be used in the Lunar Surface Electrical Properties Experiment.

2. APPLICABLE DOCUMENTS

LSP-360-12D Design Control Specification for Data Storage Electronic Assembly Instrumentation Subsystem, Grumman Aircraft Engineering Corp.

The documents called out in LSP-360-12D:

NHB 5300.4(1B) Quality Program Provisions
(Formerly NPC 200-2) for Aeronautical and Space System Contractors

3.0 Requirement

Same as LSP-360-12D except as modified above.

3.1 Materials, Parts & Processes

Materials, parts, and processes selection which are different from the Grumman procurement shall require ______________ approval. When temporary substitutions are made, drawings shall note the applicable Government specification of the alternate material.

3.1.1 Limited Life Items

The use of materials and parts, whose life is anticipated to be less than the required life of the DSEA, shall be avoided. When this type of material or elements must be used, they shall be identified to indicate date of manufacture and the anticipated end or useful life either by date or number of duty cycles. Prior to use of any item with limited life characteristics, approval shall be received from ________________.

3.2.2.1 Electrical Power

The power sources available will be a nominal 26V, single phase, 400 cps, AC system. Specified performance of the DSEA is not required during abnormal, transient, or low line voltage conditions beyond the limits specified in the following paragraphs. The DSEA shall not be damaged by exposure to the aforementioned transients or by continuous operation under low line conditions. Specified performance of the DSEA is required upon restoration of nominal power source limits. The specified performance of the DSEA shall be obtained with the input voltages having the characteristics specified in the following paragraphs.

3.2.2.1.3 AC Power

(a) Steady State Voltage Limits

The nominal voltage will be 26 $\pm$ 0.5 volts rms.

(b) Transient Voltage Limits

20 to 50 volts peak and will recover $\pm$ 5% of the nominal output voltage within 100 milliseconds. Voltage spikes, if superimposed at any point on the nominal sinusoidal wave shape will be less than 2 volts peak.

(c) Voltage Modulation

Voltage modulation shall be in accordance with MIL-STD-704, paragraph 5.1.3.6, except volts maximum amplitude shall be substituted wherever the value allowed by MIL-STD-704 exceeds 0.5 volts.

(g) Free Running Mode Frequency Deviations

In the event that synchronization of the AC power with the clock is lost, frequency limits will be 400 cps ± 10 cps. The maximum frequency drift rate will be 1 cps per minute at steady-state AC power source operating conditions.

3.2.2.11.1 DSEA Packaging

Packaging of the DSEA and its subassemblies shall be in accordance with Grumman Specification Control Drawing LSC-360-12 and Grumman Specification LSP-360-002 as applicable. Any deviation shall be substantiated as part of the detailed packaging design to the submitted by the vendor for ____________ approval.

3.2.4 Soldering Requirements

(b) Deviations from the authorized specification presently being used (either MSC-PROC-158A as amended by MSC-ASPO-5B and supplement(s), or MSC-PROC-158A as amended by MSC-ASPO-S-5C), by MSC-ASPO-S-6, MSC Supplement, shall be considered approved upon submission of written notification to ______________. Within thirty (30) days of receipt of this direction each subcontractor shall stipulate the process he is following. MSC Houston will be furnished copies of these notifications.

3.2.5.1 Maintenance Provisions

The DSEA shall be designed and constructed so that replacement of an electronic component can be readily accomplished at the vendor's, ______________, or at the test launch facilities.

3.2.7.1 Amplification Factor

The vibrational motion amplification factor on any portion of the DSEA shall be limited to a maximum of 10 where not already limited to a lower value by other design requirements. The amplification factor is defined as the total displacement of any point on the item under test, divided by the displacement of the input device. Vibration design shall be substantiated during development testing. In cases where this requirement appears difficult to accomplish, _________________ shall be consulted for direction before proceeding with the design development.

3.2.8.4 Internal Thermal Design

(c) Electronic parts (i.e., resistors, transistors, etc.) shall be restricted to an operating temperature range of +35°F to 160°F unless reliable operation can be demonstrated outside this range to the satisfaction of _______________.

3.2.10 Parts Selection

Only high reliability parts shall be used in the DSEA. As a guide in electrical parts selection, the vendor shall use the Grumman LM or the __________________ Acceptable Parts List whenever possible. Deviations from this list will require _________________ approval. The vendor shall request approval from _________________ prior to the use of any unlisted part and shall submit data to substantiate use of this part.

3.2.14 Workmanship

All phases of workmanship shall be performed in accordance with the applicable drawings, specifications and standards. Processes and manufacturing methods not covered by this specification shall be entirely suitable for the DSEA, and the workmanship shall be in accordance with high grade spacecraft practice. All processes and manufacturing methods shall be subject to ______ ______ approval. The quality of workmanship shall not degrade the reliability, performance and durability consistent with the service life and application of the DSEA.

3.3.1 Power Source

The DSEA shall operate from the 26 volts a-c, 400 cps source described in 3.2.2.1.

3.3.2 Operational Requirements

The DSEA shall record simultaneously one channel of voice data of 3.3.4 and one channel of digital time correlation data of 3.3.5.

3.3.3.3 Start Time

The DSEA transport shall reach operational stability in less than 100 milliseconds.

3.3.7 VOX Trigger Signal Delete.

3.3.7.1 Automatic VOX Operation Delete.

3.3.7.2 VOX Circuit Closure Delete.

3.3.7.3 VOX Release Time Delete.

3.3.10.1 Flight Instrumentation Selection List Delete.

3.3.10.3 Flight R&D Measurements

Measurements to be monitored for the R&D program shall include, as required, the following parameters:

(a) Temperature

(b) Humidity

(c) Power Supply Voltage.

_____________ will make the final determination of the measurement requirements and responsiblity for all R&D measurements. This determination will be made for each vehicle as dictated by the flight development program. The vendor shall provide the pickup point for those measurements determined to be his responsibility and select, purchase, and install the transducer(s) as required for same.

3.3.11 Magnetic Tape

The vendor shall exercise the choice of recording tape, subject to ______________ approval, based upon the most suitable tape for tensile strength, wear.

3.3.16 Reference Oscillator

Two wires shall be attached from the reference oscillator to connector J1 in order to lock the reference frequency to an outside source.

4. QUALITY ASSURANCE PROVISIONS

A quality assurance program will be conducted which meets the intent of NHB 5300.4(1B).

All other provision will be the same as LSP-360-12D except as modified below.

4.1 General

This section of the specification establishes the general test and inspection requirements to be followed during the DSEA test program. The vendor may propose additional tests to further increase the effectiveness of this program. The program shall consist of the following test categories:

(a) delete.

(b) delete.

(c) Acceptance tests (4.6).

4.2.1 <u>General</u>

Private, commercial or Government test facilities may be subject to ________________ approval.

4.2.6 <u>Tolerances</u>

(a) <u>Test Equipment</u>

Equipment used to measure the DSEA parameters shall have an accuracy of one order of magnitude (factor of ten) greater than the required accuracy of the measurement to be made. Deviations from this requirement shall have approval by ________________.

4.3.6 <u>Leak Detection</u>

Leakage test procedures shall be a function of the sealed enclosure physical and design parameters. The vendor shall propose methods of leak detection for sealed items to ___________ for approval.

4.3 <u>Test Procedure</u>

The vendor shall submit to _______________ test plan for the acceptance testing of the DSEA. The test procedures shall apply whenever applicable tests form a part of the vendor's program. These procedures do not constitute the test program. The test values and exposure times to be used in conjunction with these procedures are listed in the test tables.

4.4 Development Tests

Delete entire section.

4.5 Qualification Tests

Delete entire section.

4.6.1 General

The DSEA, the test apparatus and the material entering into the manufacture of articles for fulfillment of the purchase order shall be subjected to inspection by authorized ____________ representatives. At convenient time prior to the tests and after the tests, the DSEA shall be examined to determine if it conforms to all requirements of the purchase order and specifications. During the progress of tests, examinations may be made at the discretion of ________________. Acceptance test conditions shall not be more severe than expected mission conditions. DSEA(s) delivered by the vendor for use on LEM shall not contain a component or part which has been subjected to more than two (2) acceptance test programs nor component or part which has been subjected to environments of an intensity higher than acceptance test levels.

4.6.3 DSEA Acceptance Tests

Each DSEA as assembled for the inspection specified in 4.6.2 shall be subject to the tests outlined in Table III and as specified in paragraphs 4.6.3.1 through 4.6.3.6.

4.6.3.3 Leakage

Leakage test shall be performed in accordance with paragraph 4.3.6 and 4.3.7.

4.6.3.5. Additional Tests

Additional tests for the purpose of testing special features of the DSEA may be required by ________________ or proposed by the vendor. These tests shall be outlined in the test plan and shall not, in general, increase the total running time accumulated during the acceptance tests.

4.6.3.6 Final Leakage Test

After completion of all other acceptance test as listed in Table III the DSEA shall be loaded with the mission tape and sealed. After completion of a 5 minute operation check the DSEA shall be subjected to a final leak test and tested to the requirement of paragraph 4.3.7. The test procedure for the final leakage test shall be subject to ________________ approval.

4.6.5 DSEA Inspection After Test

Upon completion of the acceptance tests, the DSEA shall be subjected to a visual inspection of all working parts. If any part is found to be defective, an approved part shall be supplied to replace it, and a suitable penalty test shall be conducted at the discretion of ________________.

APPENDIX 7.1

M.I.T./CSDL

TECHNICAL PROPOSAL FOR THE

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

REVISION I

M.I.T.

CHARLES STARK DRAPER LABORATORY

CAMBRIDGE, MASSACHUSETTS

PROPOSAL NO. 70-238 Rev. 1*

VOLUME I

TECHNICAL PROPOSAL FOR THE SURFACE ELECTRICAL PROPERTIES EXPERIMENT

December 1970

*#70-238 Rev 1 replaces in its entirety Proposal #70-238.

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

TECHNICAL PROPOSAL

CONTENTS

1.0 THE CHARLES STARK DRAPER LABORATORY

The Charles Stark Draper Laboratory is a division of the Massachusetts Institute of Technology. For years it has specialized in programs dealing with the sensing, transmitting, processing and application of information as complete projects developed from system requirements. It is best known for its work in the stabilization, control, navigation and guidance of all types of vehicles, manned and unmanned, including submarine and surface ships, helicopters, missiles, aircraft and spacecraft. Some of its better known projects in these areas are Apollo, Deep Submergence Rescue Vehicle, Polaris and Poseidon.

Throughout the past decade, the Draper Laboratory has applied the broad systems knowledge developed on these programs to a variety of non-navigational functions, including biomedical instrumentation, ocean systems, computer analysis, design and programming.

The Laboratory has several buildings with more than 250,000 square feet of office and laboratory space within a few blocks of the main MIT campus in Cambridge. Presently, the Laboratory employs more than 1850 technical and non-technical personnel, maintaining professional staffs for administration, documentation, publication, security, mechanical design, drafting, quality assurance and other services which support its research and development projects. There are 710 engineers and scientists on the technical staff, holding 240 master degrees and 29 doctorates.

2.0 FACILITIES DESCRIPTION

In addition to facilities for the fabrication of flight and prototype hardware, the Draper Laboratory possesses facilities for thorough evaluation and test of space systems and hardware. Several fabrication facilities exist throughout the Laboratory;

Apparatus sufficient for design, acceptance, and qualification tests exists at various locations in the laboratory for shock, vibration, vacuum, solar vacuum, leak testing, and thermal testing.

The Draper Laboratory's special test facility is located at Bedford, Massachusetts. This facility is equipped with centrifuge, vibration table, shock equipment, altitude and space simulators. The largest centrifuge is shown in Fig. 2-1. The arm of the centrifuge is 60 feet and can reach 100G with 1500 lbs. of test equipment; the end of the arm has a counter rotating table. The centrifuge can be equipped with a vibrator as shown to provide both acceleration and vibration to simulate boost conditions. A vibration table which can provide 7,000 pound force appears in Fig. 2-2. This table can operate with sinusoidal or random vibration. Figure 2-3 shows one of two vacuum chambers capable of simulating the space environment. This chamber is 48" in diameter, has windows for the solar radiator seen in the picture and has a liquid nitrogen cold wall.

Figure 2-4 is a vacuum chamber used to make thermal measurements in vacuum. Figure 2-5 shows standard Veeco mass-spectrometry equipment used to perform

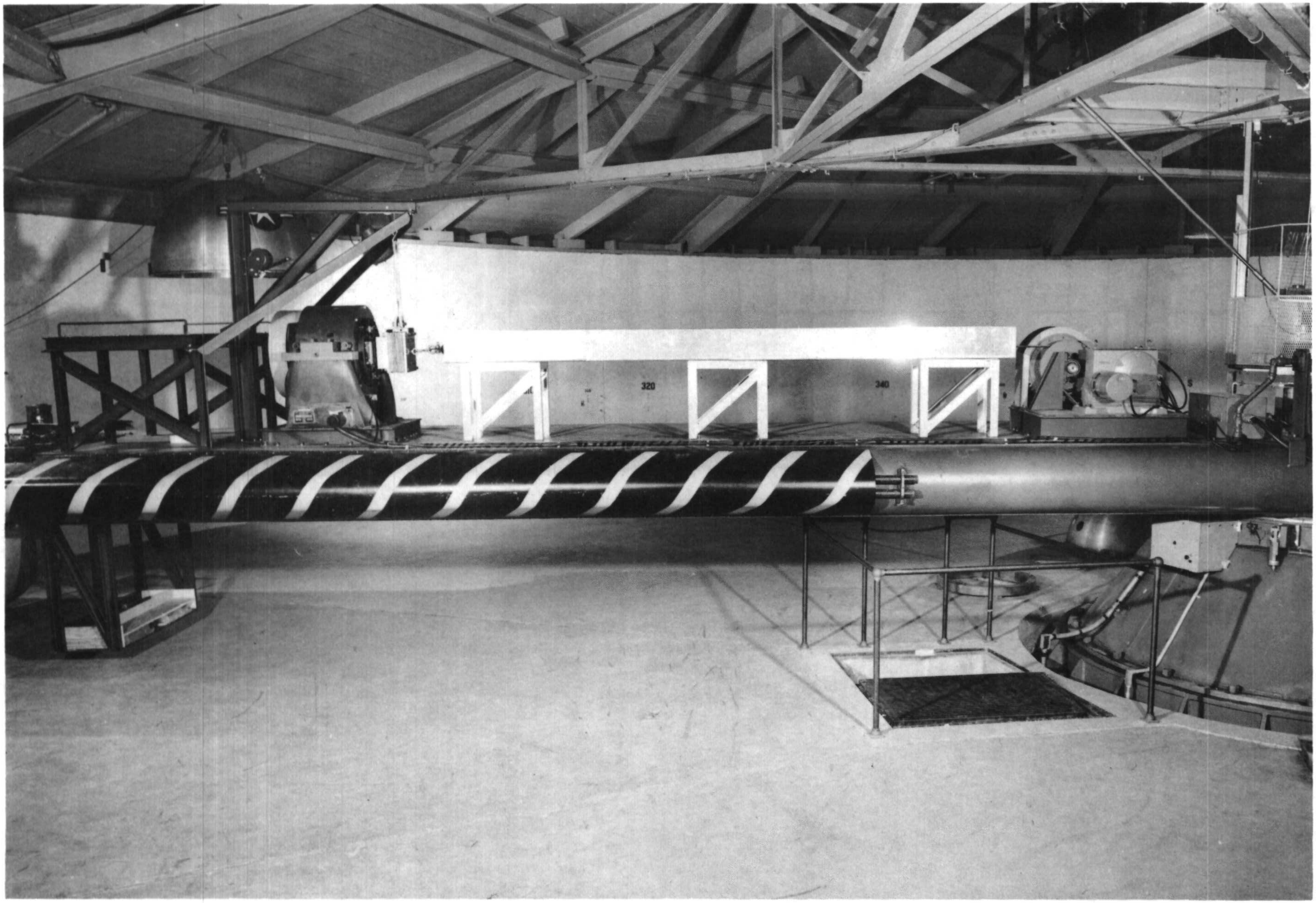


Fig. 2-1.

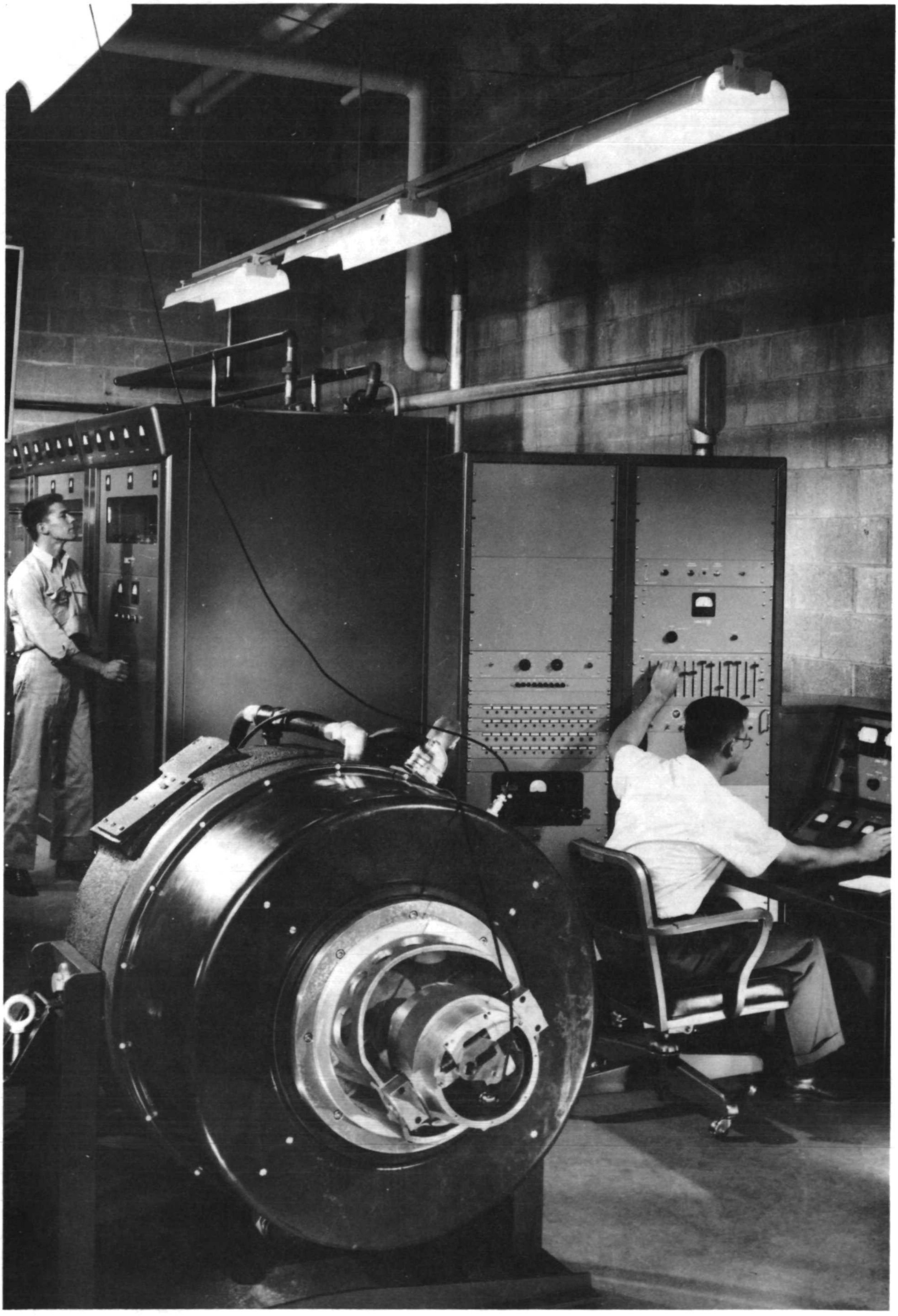


Fig. 2-2.

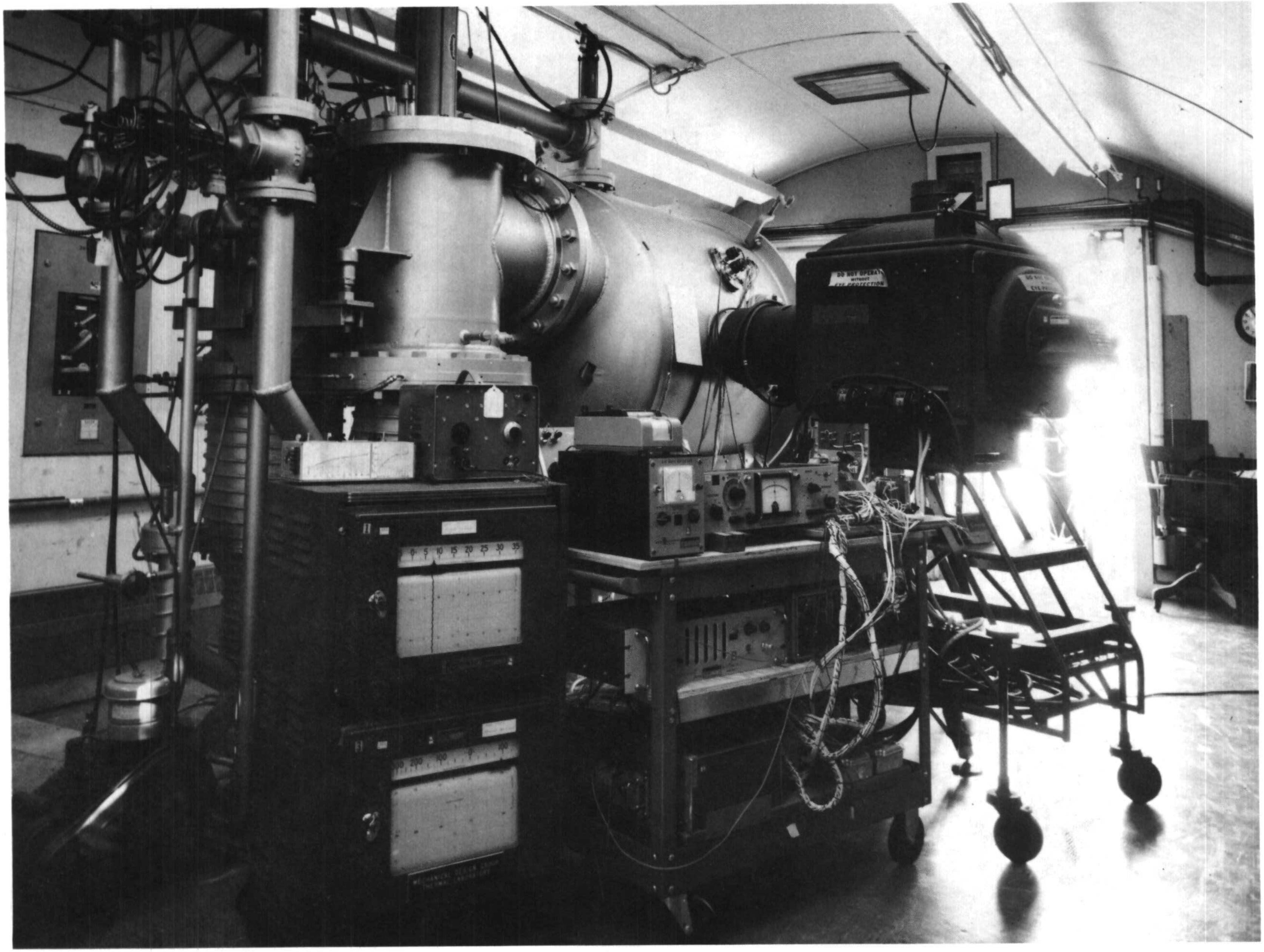


Fig. 2-3.

Fig. 2-4.

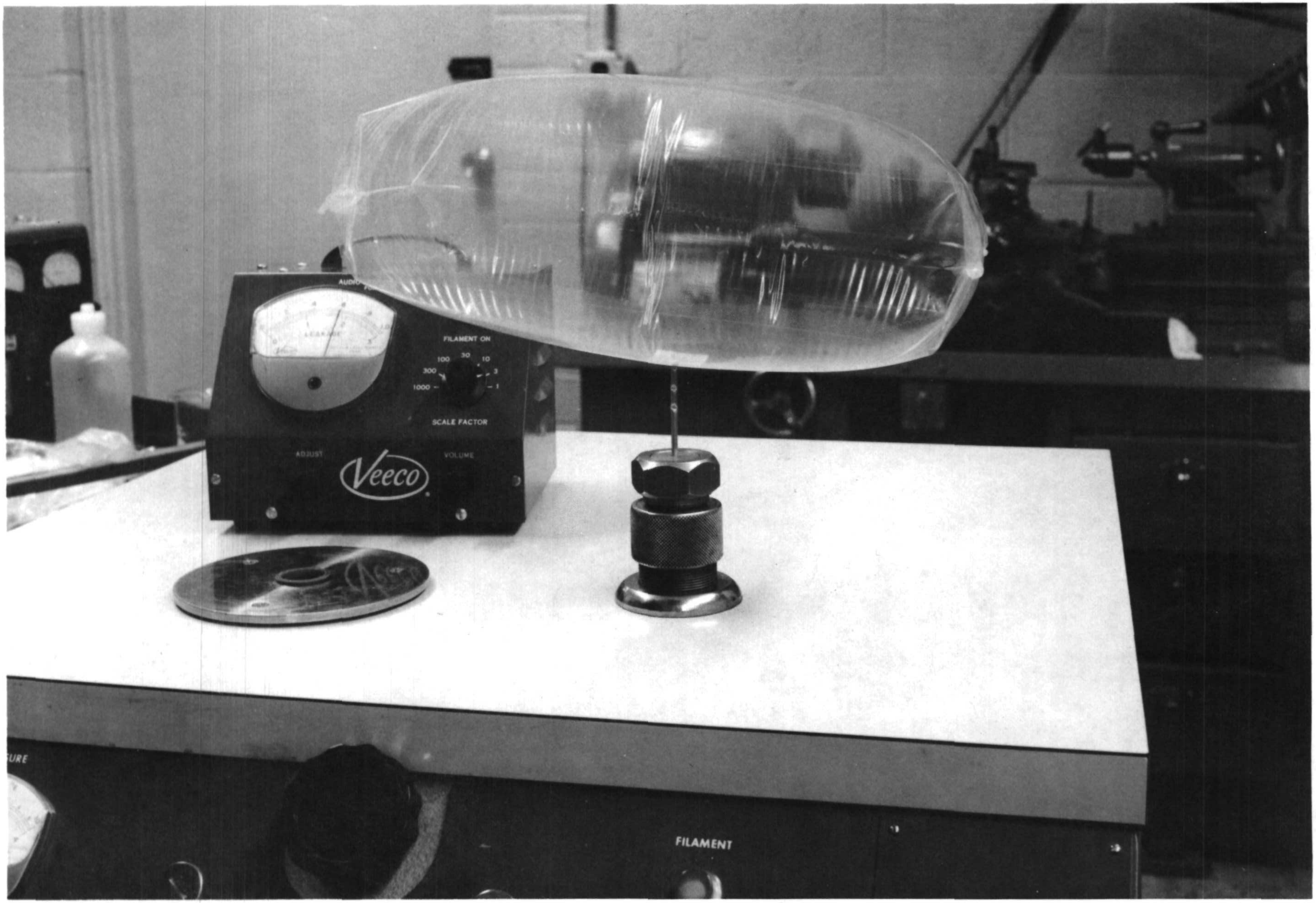


Fig. 2-5.

helium leak tests. In the photograph a calibrated leak is being measured.

Draper Laboratory R&QA Group has a Reliability Test Laboratory to perform qualification tests and failure analysis on components. Included in this laboratory are centrifuges, mechanical shock, vibration, bake, thermal shock, leak test, X-Ray, humidity, salt spray, flammability, thermal vacuum, pressure and inspection equipment. A portion of this facility appears in Fig. 2-8.

Fig. 2-8.

HUMAN FACTORS

The Apollo Display and Human Factors division developed Flight Simulation Facilities to evaluate vehicle control systems equipment and procedures for the Apollo spacecraft. Simulation facilities include mockup of the Apollo Command Module and Lunar Module and Lunar Module as well as a space navigator installed in the roof of DL-7. This group has had extensive experience working with the astronauts and solving human factors problems. The LM mockup appears in Fig. 2-6;Fig.2-7 shows the roof top space navigator with astronaut Edward White.

CLEAN ROOM FACILITIES

Draper Laboratory has a number of clean rooms used to assemble and test complex electrical and mechanical assemblies. Figure 2-9 is a PIPA assembly area and Fig. 2-10 is a gyro assembly area. An existing clean room is located adjacent to the planned lunar experiment fabrication area to be used as required.

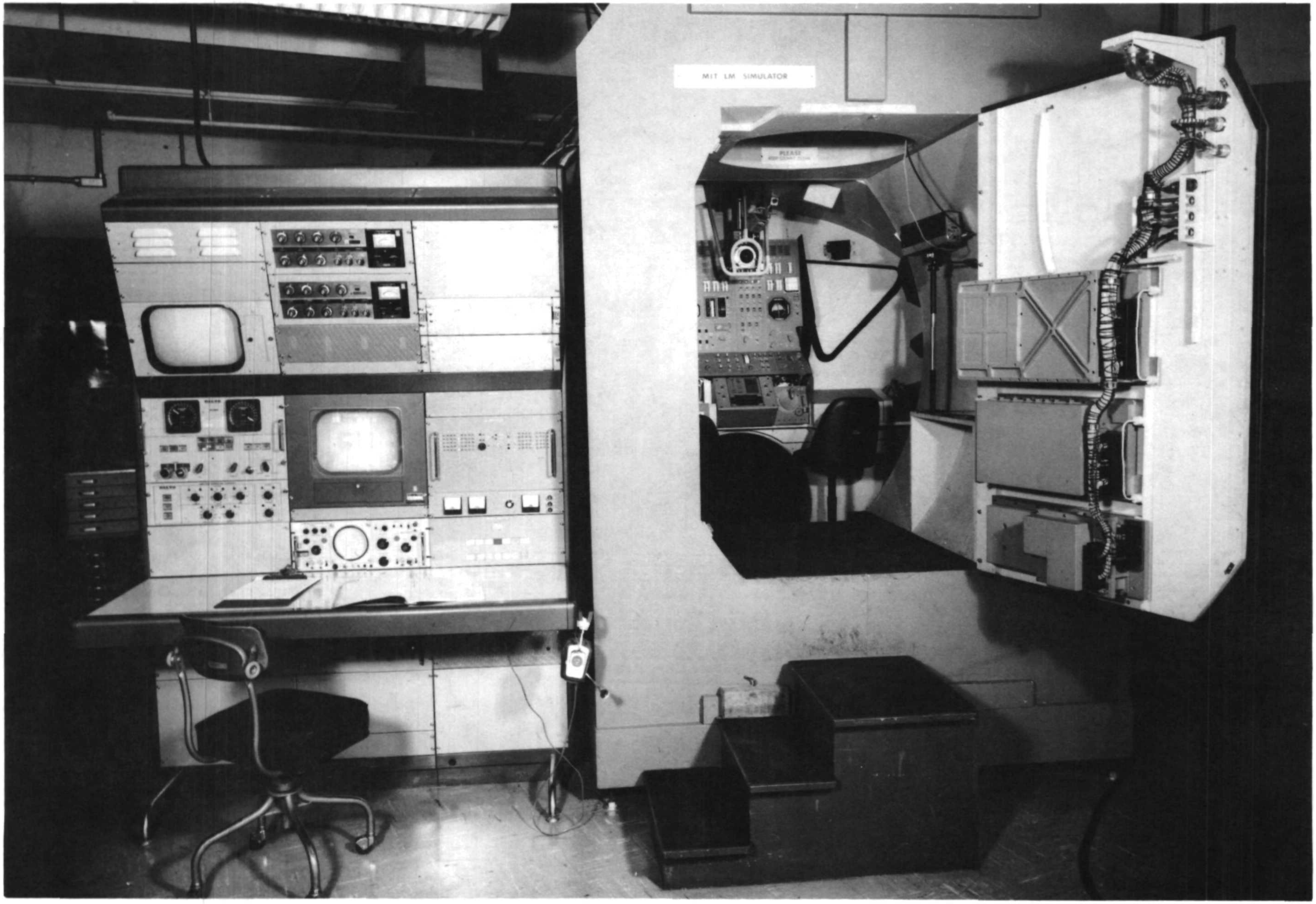


Fig. 2-6.

Fig. 2-7.

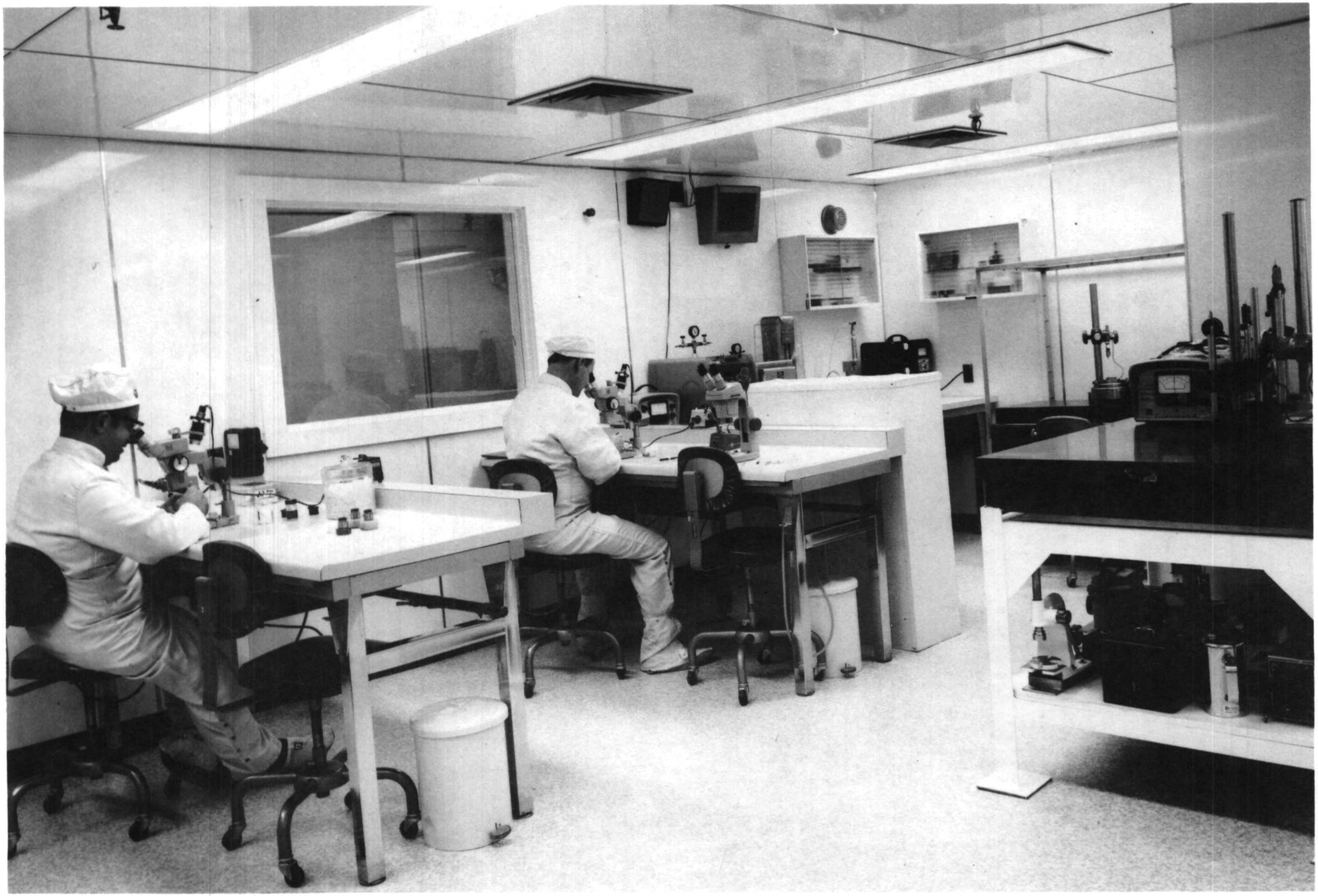
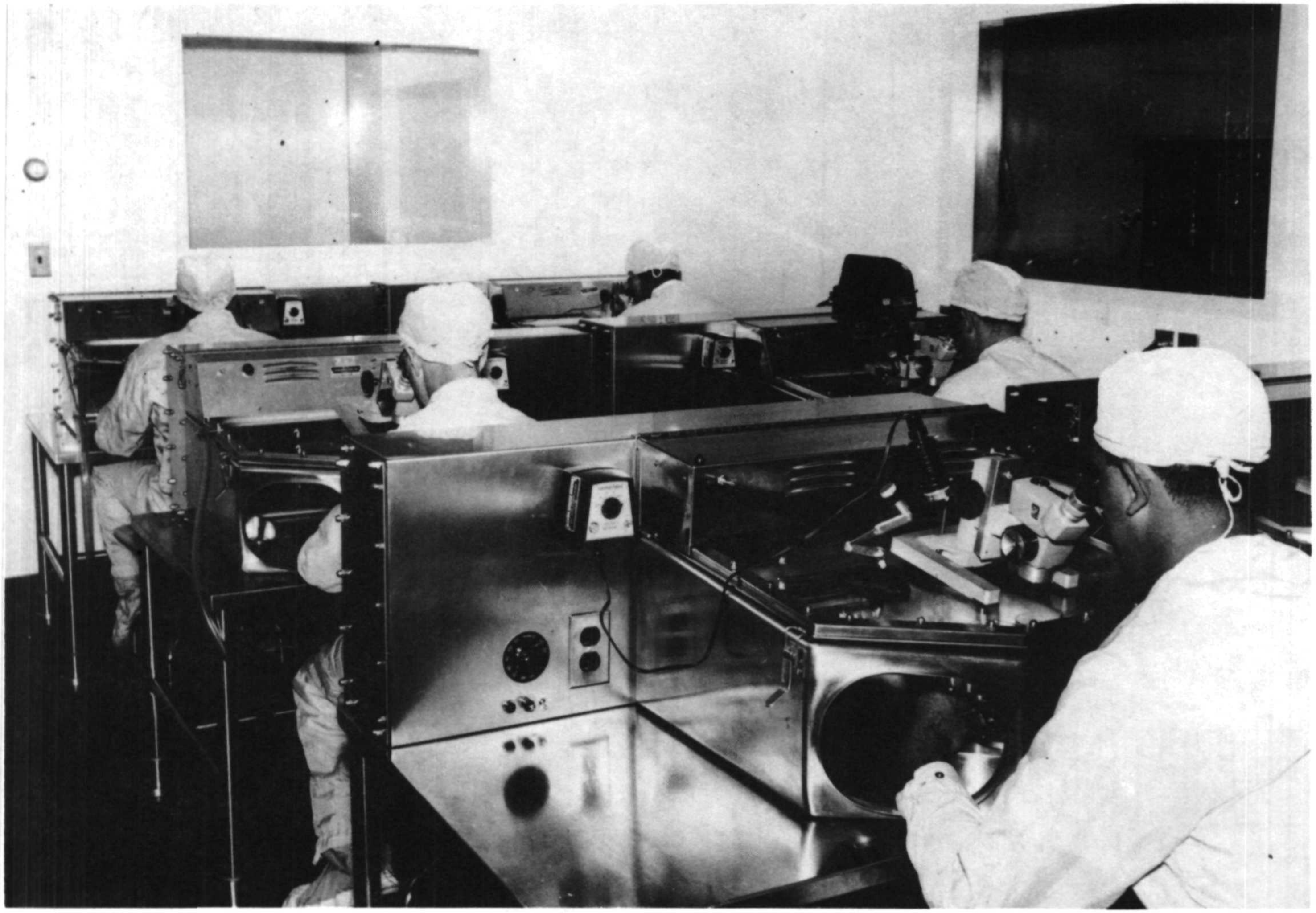


Fig. 2-9.

TYPICAL INSTRUMENTATION LABORATORY CLEAN ROOM TODAY



INSTRUMENTATION LABORATORY
Massachusetts Institute of Technology

Fig. 2-10.

SECTION 3. SEP PROGRAM DESCRIPTION

CONTENTS

3.0 Program Description

3.1 SEP Description

The object of the Surface Electrical Properties Experiment is to determine electrical characteristics of the regolith, to determine layering in the lunar subsurface, and to search for the presence of water at depth. Measurements will be made using radio interferometry techniques.

The apparatus to be used consists of a multifrequency transmitter to be deployed a short distance from the Lunar Module (LM) and a mobile receiver to collect and record field-strength data during traverses away from the LM. The equipment operates at eight discrete frequencies from 0.5 to 32 MHz. Block diagrams of the transmitter and receiver appear in Figure 3-1 and 3-2 respectively.

3.1.1 SEP Fabricated Hardware

The following items of hardware are to be fabricated for the Surface Electrical Properties Experiment.

A. Structural/Thermal Models

Assemblies built to test the mechanical and thermal design of the SEP hardware.

B. Field Evaluation Model

A collection of circuit breadboards into an electrically functional preprototype of the SEP transmitter and receiver.

C. Engineering Prototype

A non-production set of SEP hardware built for field test of the SEP. This model is to be an imitation of the flight hardware as defined by January 1971.

D. EMI Test Model

A receiver built for the specific purpose of supporting an EMI test of the LRV at MSC in January 1971. The

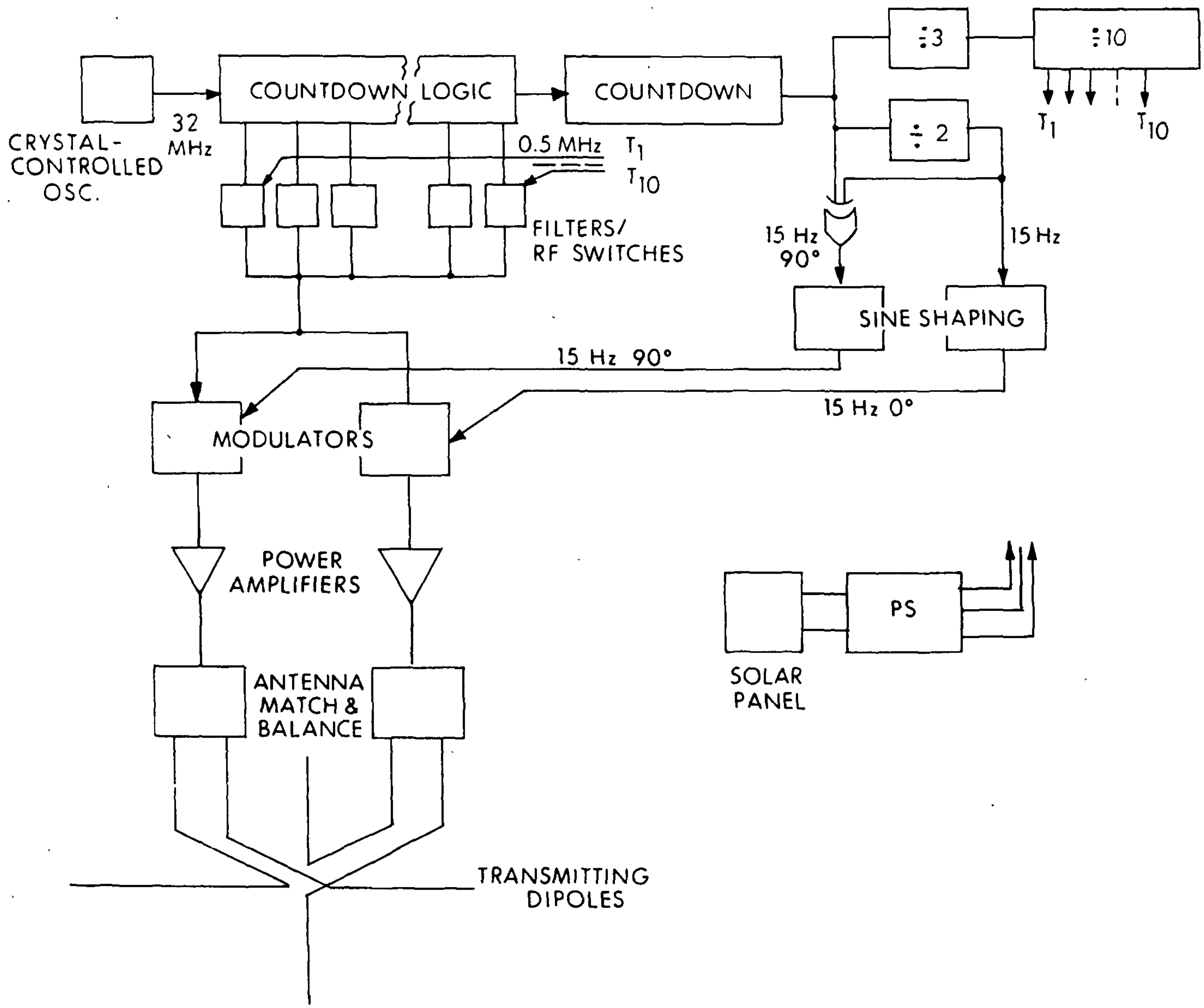


Figure 3-1 SEP Transmitter

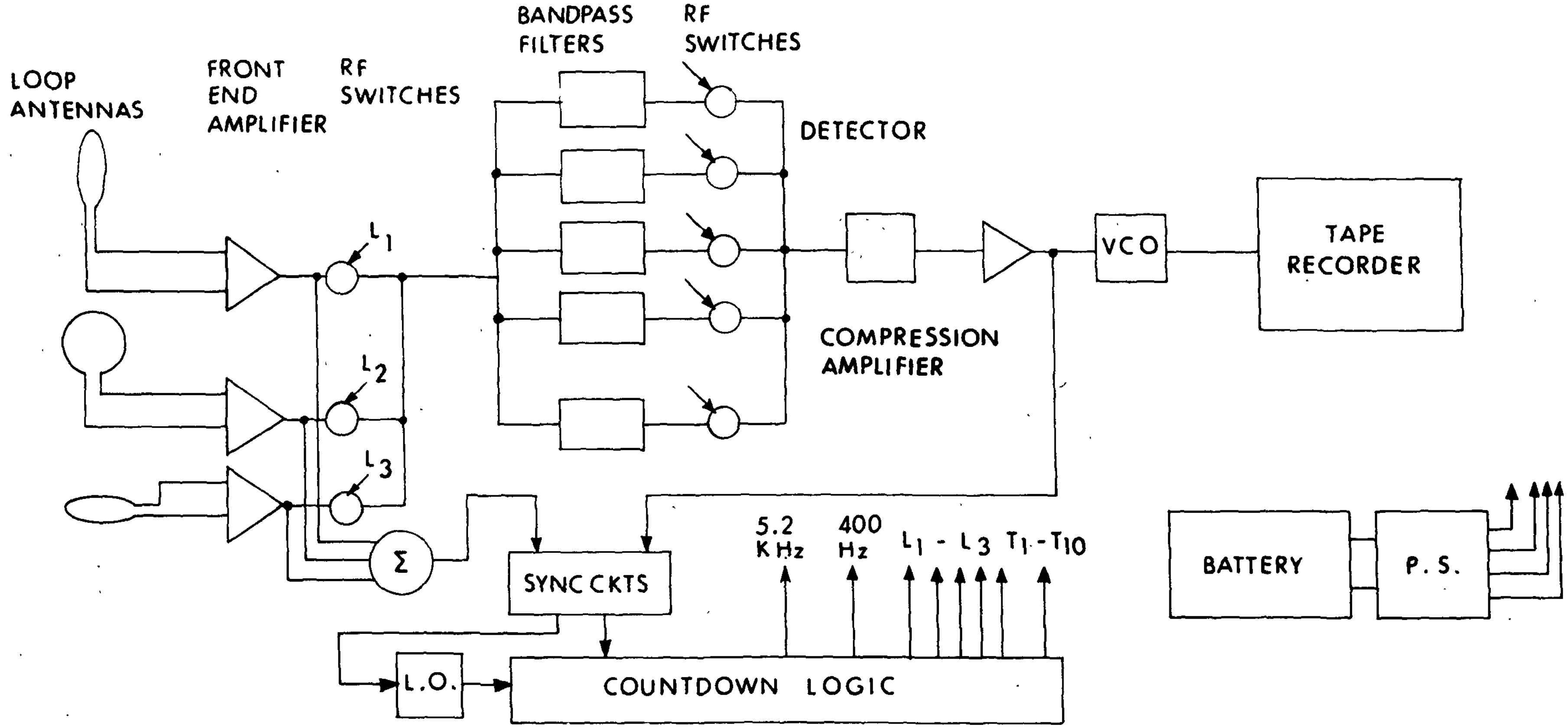


Figure 3-2 SEP Receiver

D. EMI Test Model (cont'd)

circuitry is simpler than that of the flight receiver, and a commercial tape recorder may be used.

E. Interface Mockup

To verify interfacing and mass properties of the SEP hardware. Contains no electronics.

F. Training Mockup

A non-functional mockup of the SEP hardware for astronaut training. This unit is made as close as possible to simulate 1/6g handling on earth. It contains no electronics.

G. Compatibility Unit

This unit is a production prototype built to the flight design, and serves to debug production and test procedures; the unit is destined for electromagnetic compatability testing and some pre-qualification tests, and is not built completely of flight qualified components.

H. Qualification Model

For qualification testing. This unit is representative of all production units and is the first to contain all flight qualified components.

J. First Flight Unit

K. Second Flight Unit

3.1.1.1 GSE Concept for SEP Experiment

Introduction

The Ground Support Equipment (GSE) proposed here is designed to run system level tests on the SEP Transmitter and Receiver. The design maximizes the use of commercial test equipment to reduce the number of special circuits which must be designed. Testing is done without using the antenna to avoid field intensity variations due to antenna spacing and multipath effects.

To reduce cost and schedule, the equipment is designed for manual operation. This simplified design is envisioned to be satisfactory for the limited scope of the overall program.

General Description

(See Figure 3-3, SEP Ground Support Equipment)

Included in the design are the following items of commercial test equipment:

- 1 - Random Noise Generator
- 2 - AC RMS Volmeter
- 1 - Frequency/Time Interval Counter
- 1 - Digital Voltmeter
- 3 - Regulated Power Supplies
- 1 - Wide Band Oscilloscope
- 1 - Vector Voltmeter

In addition to the commercial equipment above, the test equipment contains two fabricated panels. The GSE will be fabricated to the requirements of MSC-GSE-MEIS-2A Class II.

The GSE proposed does not include facilities for processing, reproducing, or reducing receiver-recorded magnetic tapes. The tape recorders will be accepted following satisfactorily-completed (and monitored) testing at the vendor's facility; thereafter, inspection may be done with non-elaborate equipment to be contained in the GSE.

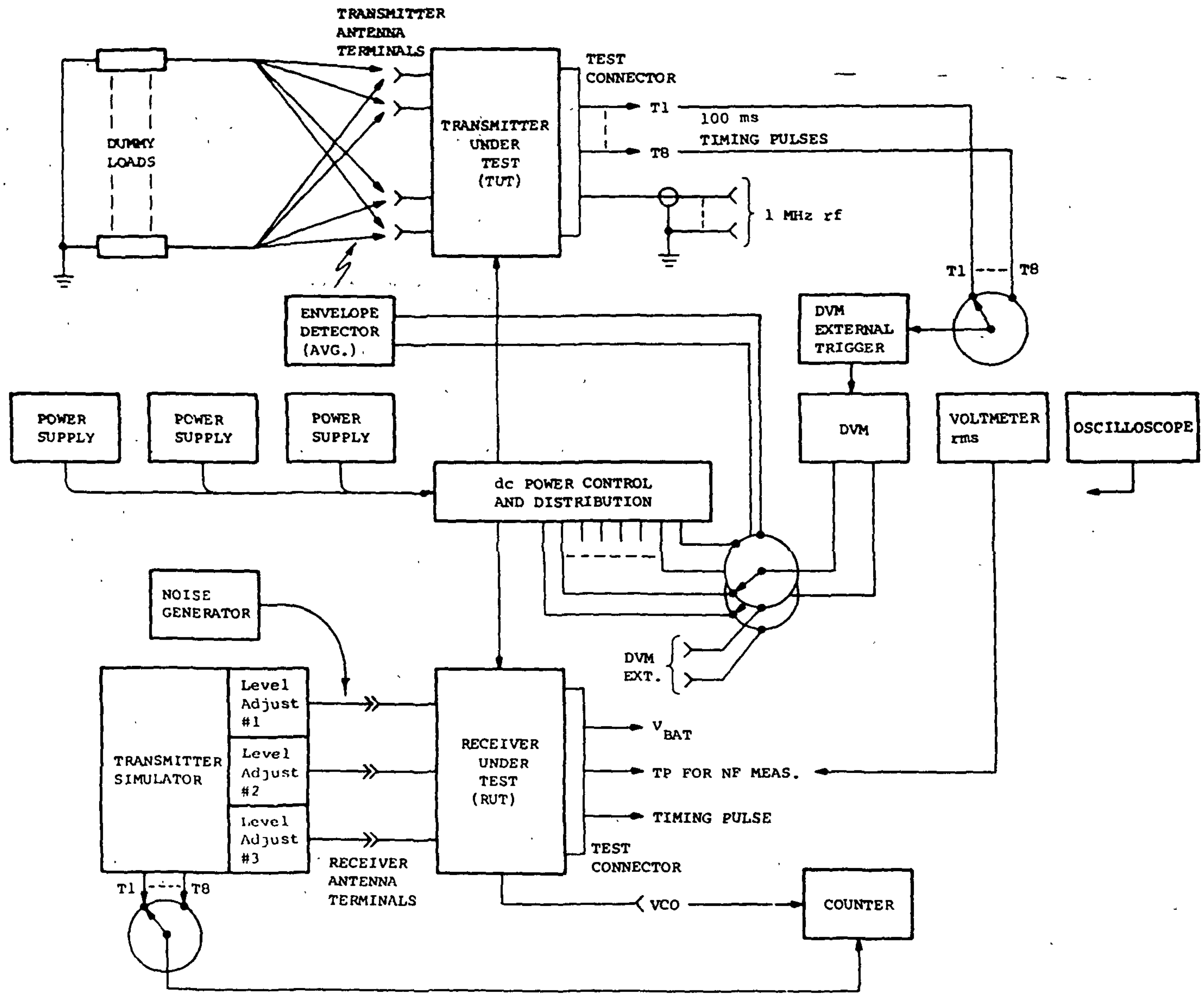


Figure 3-3 SEP Ground Support Equipment Block Diagram

3.1.1.2 Tape Processing Equipment

One set of equipment is required for processing, reproducing, and reducing tapes recorded by the SEP receiver. This hardware item is not necessary for system-level tests and will be built to the requirements of MSC-GSE-MEIS-2A Class III.

The TPE will consist of a reproduce transport rack, two audio recorder/reproducers and a computer-compatible digital tape recorder. Additional panels will contain formatting, conversion, and control circuitry as required.

The TPE is science-related equipment and as such is included in the PI proposal. It is included here for completeness only.

	Transmitter Electronics	Solar Panel	Receiver Electronics	Tape Recorder	Receiver & Transmitter Structural	Receiver & Transmitter Thermal	Notes	Fabrication Responsibility
Structural/Thermal Models	M	M	M	M	N	N		CSDL
Field Evaluation Model	N,S		N,S	S				CSDL
Engineering Prototype	N,S	N	N,S	N	N	N		CSDL
EMI Test Model			S	S				CSDL
Interface Mockup					N			CSDL
Training Mockup		M		M	M	M		CSDL
Compatibility Unit	F,N	F,N	F,N	F,N	F	F		SUB
Qualification Unit	F	F	F	F	F	F		SUB
Flight Unit 1	F	F	F	F	F	F		SUB
Flight Unit 2	F	F	F	F	F	F		SUB
GSE 1							MSC-GSE-MEIS-2A Class II	SUB
GSE 2							MSC-GSE-MEIS-2A Class II	SUB
GSE 3							MSC-GSE-MEIS-2A Class II	SUB
TPE							MSC-GSE-MEIS-2A Class III	CSDL

F : Flight-Qualified Components

N : Non-Flight-Qualified Component to Flight Configuration

S : Commercial Substitute

M : Mockup

Table 3-1. SEP Fabricated Hardware Summary

3.2 SCHEDULE

The SEP program schedule appears in Figure 3-4. Delivery of major items is as follows:

Unit	
Compatibility Model	12.5 months
Qualification Unit	13.5 months
First Flight Unit	15 months
Second Flight Unit	17.5 months
GSE 1	12.5 months
GSE 2	10.5 months
GSE 3	12.0 months
TPE	12.0 months

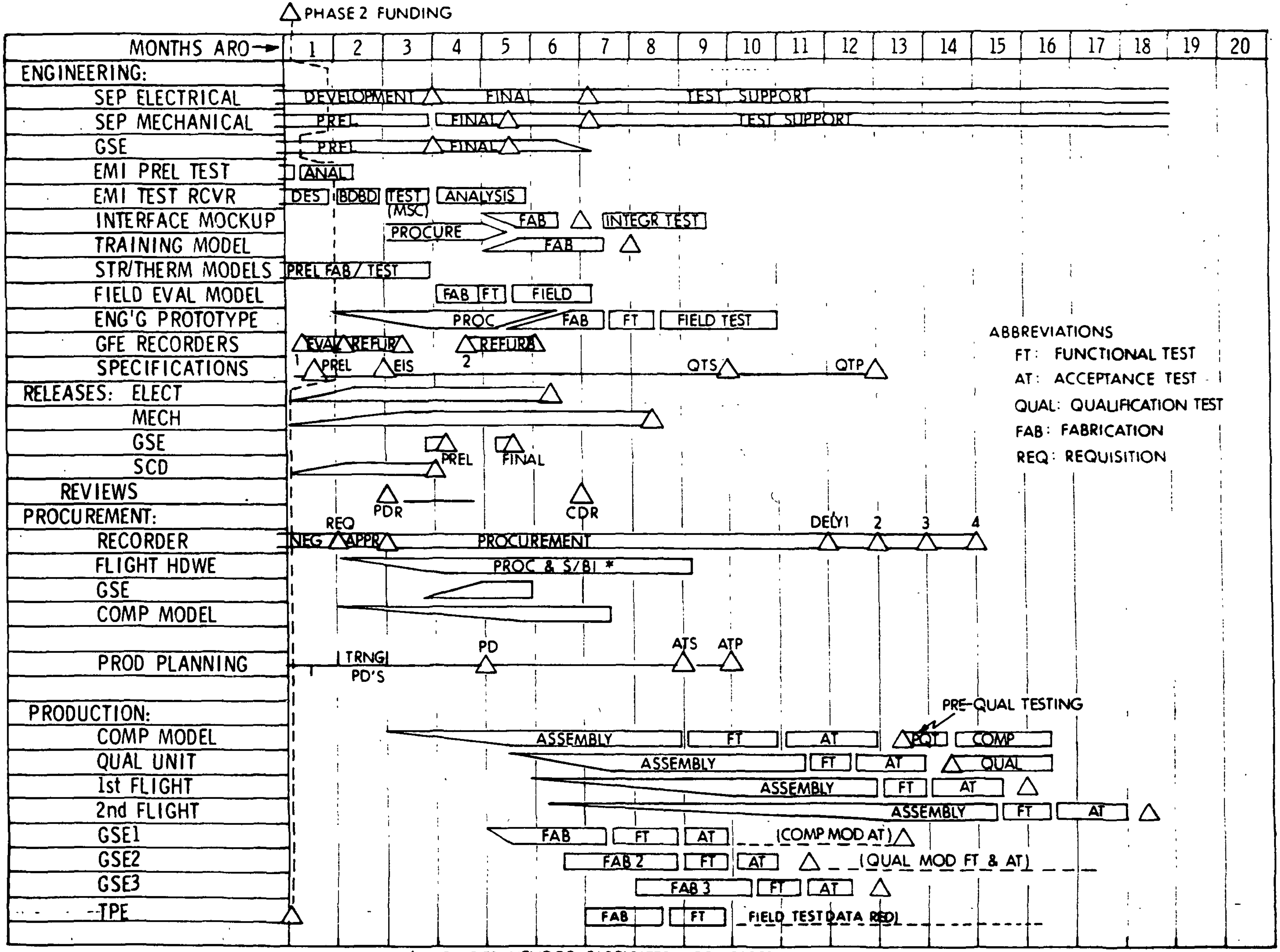
The first flight unit delivery will occur at the end of January 1972, assuming a funding go-ahead by 1 December 1970.

Procurement of components and hardware will be done as drawings become available. Specification Control Drawings for components are developed from preliminary parts lists during the early months of the program. The tape recorder procurement consists of four recorders (one for each flight-configured unit), one GSE (reproduce) rack to operate in conjunction with the Tape Processing Equipment, and the refurbishment of two recorders supplied GFE by NASA/MSC for evaluation and use with the Engineering Prototype.

The flight hardware procurement cycle shown includes vendor fabricated mechanical components. The fabrication cycles shown include kitting module assembly and module level production test. The functional test cycles include integration, final assembly, and system-level functional test.

Fabrication of flight items is started before the Critical Design Review; final assembly takes place after the CDR. Two week periods are alotted after each acceptance test cycle for Customer Acceptance Readiness Reviews.

SURFACE ELECTRICAL PROPERTIES EXPERIMENT



* INCLUDES VENDOR-FABRICATED MECH PARTS

11-5-70 JFM

Fig. 3-4

3.3 Reliability and Quality Assurance

MIT/DL and MIT/DL sub-contractor will implement applicable NASA Reliability and Quality requirements as defined in the statement of work. MIT/DL shall be responsible for establishing, providing direction for, and auditing the sub-contractor's activity. The following table reflects the division of responsibility between MIT/DL and sub-contractors.

The manner and method of such implementation shall be contained in the Reliability and Quality Plans to be submitted as required by the statement of work. For MIT/DL these are as defined by MIT/DL Quality Operating Procedures which are included with this proposal as Appendix I.

The following pages contain a matrix showing the relationship between the NASA requirements, existing MIT/DL Quality Operating Procedures, R&QA Plans, and the degree of compliance. Specific comments on certain work statement requirements are also included under comments on Exhibit A Appendix I and Exhibit A Appendix II.

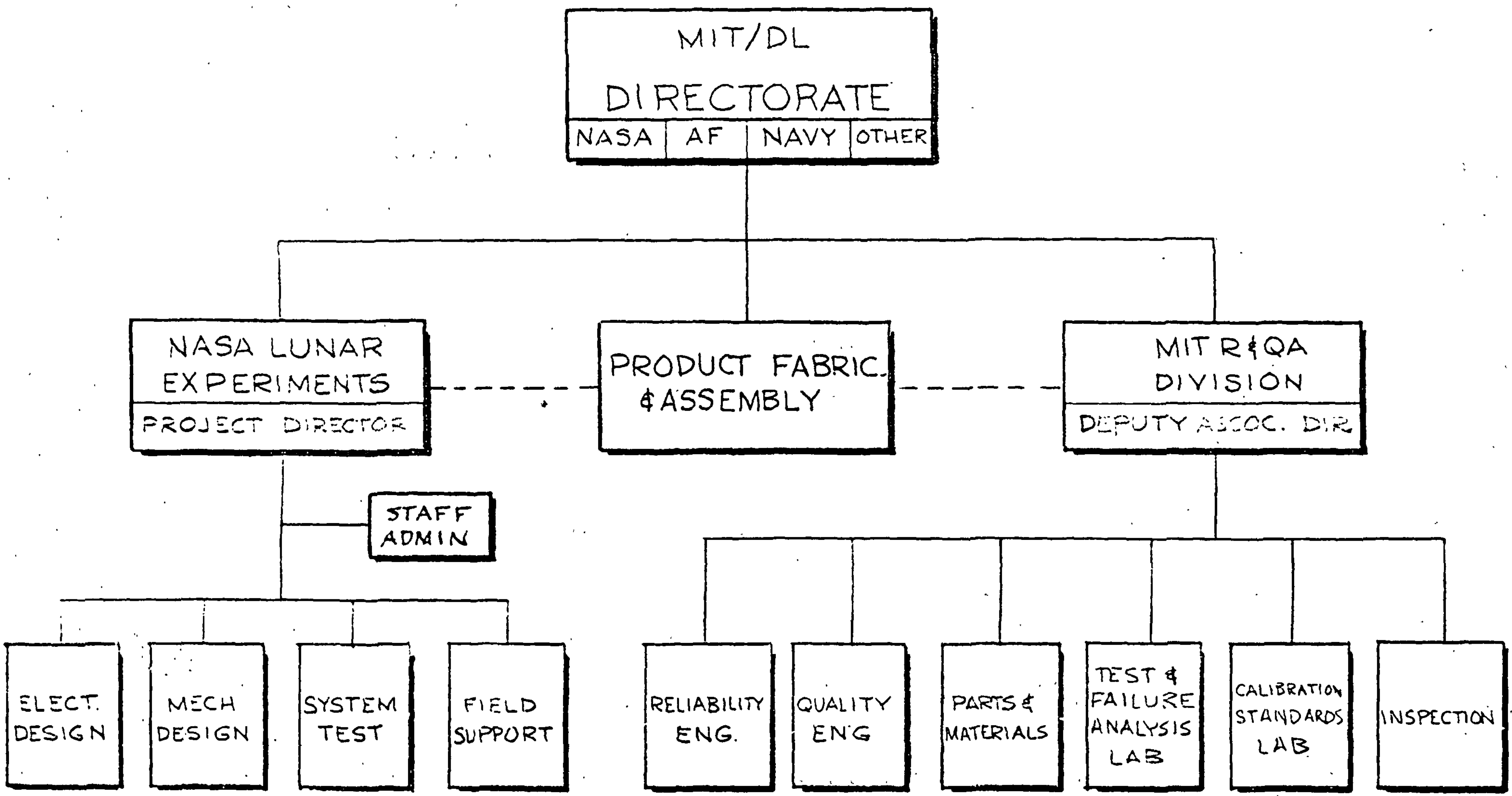
ACTIVITY	MIT/DL	SUB-CONTRACTOR
Program Plans, Management, and Direction	R	S
Design Reviews, FMEA	R	S
Parts and Materials, Selection Application and Specification	R	S
Parts and Materials Evaluation and Qualification	R	-
Vendor Surveys, Vendor Controls	R	R
Sub-Contractor Audits, Source Inspection	R	S
Production, Inspection and Test Planning	M	R

ACTIVITY	MIT/DL	SUB-CONTRACTOR
In-Process Inspection	-	R
Final Assembly and Test	M	R
MRB	M	R
Failure Reporting, Failure Analysis, and Corrective Action	M	R
Qualification Tests	M	R

R - Responsibility

S - Support

M - Monitoring



R&QA ORGANIZATIONAL RELATIONSHIP

Quality Requirements Compliance Matrix

NASA Req. NHB 5300.4 (1B)	Applicable MIT Doc.'s			Compliance			Remarks
	QOP's	QA Plan	Rel. Plan	Full	Partial	None	
Organization 1B201		X	X	X			See proposal
Training 1B202	017	X		X			
Quality Audits 1B205				X			QOP to be written
Design and Development Controls Chapter 3				X			See Configuration Management Plan E2509
Identification and Data Retrieval, Chapter 4	005 006			X			See Configuration Plan Design Documents
Procurement Sources 1B501	003 015			X			
Procurement Documents 1B[illegible]2	003			X			
Source Insp. 1B503, 1B504	003			X			
Receiving Inspection 1B505, 1B506	004			X			
Supplier Rating System 1B507						X	Not applicable
Supplier Surveys 1B508	003			X			
Supplier Coordination 1B509, 1B510	003			X			
Fabrication Operations 1B600	006			X			See Mfg. Plan
Article Controls 1[illegible]01	005, 006 007			X			
Cleanliness Control 1B602				X			QOP to be written as design requirements defin

Quality Requirements Compliance Matrix

NASA Req. NHB 5300.4 (1B)	Applicable MIT Doc.'s QOP's	QA Plan	Rel. Plan	Compliance Full	Partial	None	Remarks
Process Controls, Stds. 1B603, 1B604	008			X			
Inspection & Test Planning 1B701	006, 008, 009			X			
Test Specifications 1B702, 1B703, 1B704	002 006			X			
Inspection & Test Performance 1B705, 1B707	006 009			X			
Record of Inspection & Test 1B706	006			X			
Non Conforming Material 1B8	006 007			X			
Metrology Controls 1B9	012			X			
Stamp Controls 1B10	004 006			X			
Handling, Storage, Shipping	004				X		QOP to be written as design requirements determined
Sampling Plans 1B12						X	Not applicable 100% Inspection planned
Control of GFP 1B13	014			X			

	QOP 003	QOP 018	QOP 002	QOP 011	QOP 015	QOP 016	Rel. Plan	Des. Eng.									Remarks
Applicable Prev. Data 2.0							F										
Rel. Prog. Sub-Cont. 4.0	F																
Rel. Prog. Rev.&Ct'ls 5.0							F										
Design Spec's 6.0								F									
FMECA 8.0		F															
Des. Rev. 9.0			F														
Fail. Rpt'g & Correct. 10.0				F													
Testing & Rel. Eval. 11.0						P											Qualification testing will be done, but no reliability life tests are planned.
Limited Life Prog. 12.0							F										
Parts & Mat. Program 13.0					F												
Rel. Doc. Req'ts. 14.0							F										

RELATIONSHIP BETWEEN R&QA PROCEDURES

AND

RELIABILITY PROGRAM REQUIREMENTS

(Appendix II of Work Statement)

3.4 CONFIGURATION MANAGEMENT

The MIT Configuration Management Plan (E-2509) is attached as Appendix II.

3.5 SEP FABRICATION PLAN

Fabrication of the four flight-configured instruments and the three sets of GSE will be done under sub-contract by Raytheon Company (see Appendix III Volume I.)

3.6 TEST PLAN

This plan describes the test activities to be performed for verification of the experiment concept, design, and fabrication. Procedures and documentation for Acceptance, Qualification, and Special Tests are outlined in the NASA Experiments Reliability and Quality Assurance Plan, Appendix I.

The contents of this plan are as follows:

3.6.1 Experiment and Design Verification Tests

This group of tests is used to verify the feasibility of the experiment concept and to verify the mechanical and electrical design. The tests must be complete and detailed so as to insure that all environmental conditions can be met by the equipment, and that the object of the experiment can be accomplished with the maximum probability of success.

3.6.1.1 Experiment Verification

In addition to the present glacier test equipment, a field-evaluation breadboard and a prototype of the experiment which incorporates all of the electrical and mechanical features of the future flight models will be built. Because of the high moisture content of the earth soil, the only field test that can be performed which will simulate the moon's dielectric properties is on an ice field or glacier. A glacier with a known ice thickness will be ideal test medium for the experiment to verify the concept and design. Some of the tests to be performed on the glacier are:

1. Measure the efficiency of a precut calculated antenna at design frequency with antenna deployed on the ice.
2. Vary transmitter frequency to determine the true resonant frequency of the antenna.
3. Conduct traverses in the manner proposed for the lunar surface experiment, automatically recording results.
4. Conduct traverse using both automatic recording and hand data-logging for later comparison.
5. Assess ranging capability by comparison of reduced ranging information with measured range.

6. Evaluate the problems of antenna deployment.

3.6.1.2 Design Verification Tests

1. For verification of the electrical, mechanical, and thermal design, the following tests are required.

   a. True power dissipation of components and subassemblies as a function of usage, temperature, and input voltage. These tests form the basis for, and cross-check of, the thermal and mechanical design.

   b. Detection of critical parameters which are required for proper circuit operation as a function of voltage and temperature. This data is an input to the component engineer.

2. Component testing:

   These are tests to verify that any critical specifications required of components can be met, to verify that the basic component design is adequate, to detect unscreenable failure modes, to determine screening tests that do not introduce new failure modes, to determine tests that can screen out random failures, and to insure that the product line maintains a quality standard.

3. Thermal Verification Testing: These tests verify that the electrical andmechanical design is adequate to meet the thermal environment. Measurement of quantities for verification of design temperature limits for components and subassemblies is a primary output of these tests. These tests will be conducted both at atmospheric pressure and in vacuum, where feasible, as a function of temperature to completely

simulate both lunar and flight environment. Testing of a thermal mockup in a solar chamber is included here.

4. Toxicity and Flammability Test: Any material not previously tested and accepted for toxicity or flammability must be subject to test.

5. Human Factors Exercise" Antenna deployment, equipment operation, and tape recovery must all be tested to verify that the task can be performed by an astronaut on the moon.

6. Modeling: Antenna modeling and test under controlled conditions will be done to investigate aspects of the antenna design and mission constraints that could impact the ability to recover the data. Tests will be conducted to determine transmitter antenna patterns under varying conditions of deployment and mission environments.

7. Mechanical Environmental Testing will be done to assist and verify the mechanical and structural design.

3.6.2 Production Test Items

3.6.2.1 Component Test - Electrical

All incoming electrical components must be tested to insure that component quality has been maintained. If applicable, some components will be subject to screen and burn-in. The decision as to the type and degree of testing will depend on the output of the component evaluation and the degree that the units were tested at the vendor.

Components to be Evaluated

1. Semiconductors
2. Crystal oscillators and filters
3. Tape unit
4. Batteries
5. Resistors
6. Capacitors
7. Transformers
8. Solar Panel
9. Inductors
10. Switches.

3.6.2.2 Component Test - Mechanical

All incoming mechanical parts will be inspected and all critical dimensions measured to insure that the parts comply with design specification drawings.

3.6.2.3 Production Test

All modules and sub-modules and final assemblies must be tested to insure that the units will pass the acceptance test. Some of the tests to be performed are:

1. Leak Test
2. Operational Thermal Cycle
3. Operational Vibration
4. RF Output Into a Dummy Load
5. Insulation Resistance of Antenna and Applicable Sections of the Assembly
6. Continuity as Applicable
7. Voltage Margins, Ambient and Temperature Extremes
8. Power Dissipation
9. Weight
10. Electrical Operational Test
11. Crystal Frequency Short Term Stability

3.6.3 Acceptance Test

The acceptance test must verify that the manufacturing workmanship criteria have been met and that all components are functioning properly. No test should be included that would shorten the operational life of the equipment. Some of the tests to be performed are:

1. Leak Test
2. Operational Thermal Cycle
3. Operational Vibration

4. RF Output into Dummy Load
5. Insulation Resistance Where Applicable
6. Continuity where Applicable
7. Voltage Margin at Ambient and Thermal Extremes
8. Electrical Test of Outputs at Voltage and Temperature Extremes
9. Crystal Frequency Short Term Stability
10. Weight
11. Power Dissipation
12. S/C Installation
13. Tape Recorder Reproduction Stability
14. Operational Vacuum, High and Low Temperature Environment.

3.6.4 Qualification Test

The qualification testing is a series of tests designed to stress the equipment up to and beyond the environmental limits so as to establish confidence in the equipment. The purpose is to evaluate the design, the workmanship, and to detect any incipient system failure modes not detected to date. In order for the test to be valid the equipment must be representative of present and future production equipment not a hand crafted model built to pass the qualification test. The qualification model is not to be used for flight; therefore tests which are unsuitable for flight equipment because of excessive stress conditions are suitable for the qualification model. The series of tests must be so designed as to gather the greatest amount of data with any wearout or destructive test performed last. The environments to be included are:

1. Vibration - all axes
2. Shock

3. Acceleration
4. Thermal cycle
5. Thermal shock
6. Vacuum high and low temperature
7. Sun radiation in vacuum
8. Leak test
9. EMI
10. Salt spray and corrosion
11. Exposure to dust
12. Acoustic noise
13. Humidity

Abbreviated qualification-level testing will be done prior to the actual qualification test on the Qualification Unit. Specific tests (vibration, shock, thermal vacuum) will be performed on the Compatibility unit to increase confidence in the equipment design before the actual Qualification Test.

SECTION 4. COMMENTS AND RECOMMENDED CHANGES TO WORK PACKAGE TASKS

CONTENTS

4.0 MIT accepts the condition of the work package received with RFP VC931-88-1-165P with the following reservations and alternatives. "No comment" indicates that MIT concurs with and/or will comply with the provisions of the specific article or section.

4.1 PROPOSED CONTRACT SCHEDULE

Article I. MIT concurs with the provisions of this article.

Article II.

5. Flight Unit #2 delivery will occur at 17.5 months.

6. Qualification Unit delivery will occur at 13.5 months after receipt of contract.

10. Compatibility Model delivery will occur at 12.5 months after receipt of contract.

Article III - IX.

MIT concurs with the provisions of these articles.

Article X.

Article XI.

Article XII - XVI.

No comment.

Article XVI.

See comments below under Exhibit "A", Appendix IV.

Article XVIII.

See comments below under Exhibit "A", Appendix III.

Article XIX.

No comment.

Article XX.

No comment.

Articles XXI - XXV.

No comment.

Article XXVI.

Article XXVII.

4.2 STATEMENT OF WORK

EXHIBIT A

1.0	No comment.
2.0	No comment.
3.1.a	See comment under 5.2.13.
3.1.b	No comment.
3.1.c	See comments under Exhibit A, Appendix I.
3.1.d	See comments under Exhibit A, Appendix II.
3.1.e	See comments under Exhibit A, Appendix III.
3.1.f	See comments under Exhibit A, Appendix IV.
3.1.g	No comment.
3.1.h	See comments under Section 5.0.
3.1.i	No comment.
3.1.j	See comments under Section 5.0 and E-2509.
3.2	No comment.
3.1.1	MIT assumes that Table I is the list of equipment contained in Article II. See comments under Article II.
3.3.2	MIT assumes that Table I is the list of equipment contained in Article II. Further, the ground support equipment will be in accordance with MSC-GSE-MEIS-2A Class II.
3.4	No comment.
3.5	No comment.

SECTION 4. Definition d. Add - The prototype for the SEP experiment is intended for glacier testing of the experiment and hardware design.

SECTION 4. Definition f. Insert - "Interface Mockup" in place of "Mass Mock-Up Hardware".

SECTION 4. Definition g. Insert - "Training Mockup" in place of "High-Fidelity Mock-Up".

SECTION 4. Add definition h. as follows:

h. Compatibility Model. A model equivalent in configuration to the flight hardware that does not contain all flight-qualified components. This unit serves as a production prototype and will be subjected to abbreviated qualification level testing.

5.1. No comment.

5.2. No comment.

5.2.1. No comment.

5.2.2. End Item Specifications will be prepared for the flight-configured units and the GSE.

5.2.3. Engineering drawing will be type II so that schedules may be maintained.

5.2.4. See comments under Exhibit A, Appendix I.

5.2.5. No comment.

5.2.6. No comment.

5.2.7. No comment.

5.2.8. No comment.

5.2.9. No comment.

5.2.10. No comment.

5.2.11. See comments under Exhibit A, Appendix II.

5.2.12. See comments under Exhibit A, Appendix IV.

5.2.13. No comment.

5.2.14. No comment.

5.2.15. No comment.

5.2.16. No comment.

5.2.17 No comment.

5.2.18 No comment.

5.2.19 Definition - Insert "Compatibility Unit" in place of "prototype".

5.2.20b As the equipment being developed is not overly complex, it is felt by MIT/DL that sufficient proof of performance, traceability and reliability can be proven without the extensive Test Documentation requested. MIT/DL proposes that only qualification and acceptance documents be delivered. Generation of the required documentation requires extensive manpower and time to accomplish. As delivery schedules are critical, this approach is one way to assure that they will be met.

5.2.21 No comment.

5.2.22 No comment.

5.2.23 No comment.

TABLE II. Table II lists Interface Control Documentation as Type II. ICD's will be Type I in accordance with 5.2.23 of Exhibit A.

4.3 Comments on Exhibit A, Appendix I

Quality Program Requirements

Paragraph 1.0	Quality Assurance Program Provision The requirements of NASA Reliability and Quality Assurance Publication, NHB 5300.4 (4B) will be met as indicated in the matrix chart.
Paragraph 2.0	Soldering Requirement for Electrical Connections AH soldering operations performed on the SEP will be in compliance with NHB 5300.4 (3A). "Requirements for Soldered Electrical Connections".
Paragraph 3.0	Resistance Welding of Electronic Module Connections MIT/DL has developed and prepared welding specifications that are used in the fabrication of Apollo Guidance and Control Systems. These will be used to the extent they are applicable. Listed below are the MIT welding specifications: ND1002256 Parallel Gap Welding Specification ND1002005 Resistance Welding Specification Additionally, all personnel performing welding operations will be trained and certified.
Paragraph 4.0	Corrosion Prevention MIT/DL will comply with the provisions as stated.
Paragraph 5.0	Contamination Control Requirements MIT/DL will comply with the provisions to the degree they are applicable.

Paragraph 6.0	Manned Spacecraft Criteria and Standards
	MIT/DL will comply in general with the design considerations and practices of MSCM 3080. Areas wherein design considerations or constraints will require departure will be brought to the attention of MSC.
Paragraph 7.0	Acceptance Data Package
	The items listed for the data package will be provided.

4.4 Comments on Exhibit A, Appendix II.

Reliability Program Requirements.

Paragraph 1.0 — Introduction

MIT/DL with sub-contractor support will provide the necessary staffing to effectively accomplish the tasks identified as being essential to program success. MIT/DL has appointed one individual to the responsibility of overseeing the Reliability and Quality Assurance activities for the NASA Experiments Programs. This individual will be supported by the R&QA staff to the degree shown in the man-loading budget. In all other respects MIT/DL will comply with the statements of paragraph 1.0.

Paragraph 2.0 — Applicability of Previous Reliability Data

MIT/DL will utilize wherever possible previous applicable data. Where such data are lacking or are unavailable, MIT/DL will identify the method by which it will obtain the necessary data. An approved parts and materials list will be created specifically for the NASA Experiments Programs, and the qualification status of each item will be identified. See QOP-015.

Paragraph 3.0. — Reliability Program Plan

MIT/DL has prepared a preliminary set of R&QA procedures which will provide the basis for program planning and negotiation. A Reliability Program Plan will be prepared which will detail the specific tasks agreed upon. The contents of the plan will follow the provisions of paragraph 3.0.

Paragraph 4.0. — Relaibility Program for Major Subcontracts

MIT will comply with the provisions of this paragraph in accordance with QOP-003.

Paragraph 5.0	Reliability Program Review and Controls
	Continuous monitoring of the reliability program will be conducted by the Project R&QA engineer. In addition, regularly scheduled program reviews will provide a tribunal for judging progress.
Paragraph 6.0	Design Specifications
	The MIT/DL generated "NASA Experiments R&QA Plan" defines the participation of the R&QA group in design specification. These may be found in QOP-002, Design Review, QOP-015, Parts, and QOP-003, Supplier Control. By means of these QOPs (Quality Operating Procedure) the R&QA group provides guidance in design specification and surveillance of all specifications that may affect the reliability or quality of the end item.
	For this program, there are no quantitative reliability goals established; therefore, no apportioned reliabilities will be made.
Paragraph 7.0	Reliability Prediction and Estimation
	Not applicable per statement of work.
Paragraph 8.0	Failure Mode, Effect, and Criticality Analyses
	In the MIT/DL prepared R&QA plan for NASA Experiments, QOP-018 describes the procedure to be followed for FMEA.
Paragraph 8.1	MIT/DL concurs with the content of the FMEA report. Supporting documentation will be available for NASA review. MIT/DL views the FMEA as a tool to be used in design reviews for identifying potentially critical failures and as an aid in establishing test and inspection points during fabrication and assembly, rather than as a separate reliability task.

Paragraph 8.2	FMEA Preparation
	The basic technique that will be followed and reported on is one of first preparing a functional block diagram of the system, identifying all input and output signals, and then hypothesizing the most probable failure modes that would be detrimental to the experiment success. This will be done from the top down to the component level in the form of a fault tree analysis.
Paragraph 8.3	FMEA Format Entries
	Format to be as described in QOP-018.
Paragraph 9.0	Design Review Program
	A description of the MIT/DL design review procedures are contained in QOP-002. It is intended these will be followed for the NASA Experiments Programs. The procedures of QOP-002 are compatible with the provisions of paragraph 9.0.
Paragraph 10.0	Failure Reporting and Correction
	MIT/DL will comply with the requirements of this paragraph. The bulk of failure reporting and corrective action will be done by the sub-contractor.
Paragraph 10.1	Failure Report Submittal
	MIT/DL concurs with the provisions of this paragraph.
Paragraph 10.2	Failure Analysis and Corrective Actions
	MIT/DL concurs with the provision of this paragraph.
Paragraph 11.0	Testing and Reliability (Qualification Program)
	MIT/DL will conduct a qualification and evaluation program in accordance with the procedures of QOP-016. These procedures are compatible

Paragraph 11.0 (cont)	with the provisions of this paragraph. However, it is not intended that the tests will be run to establish quantitative relaibility values, since there will not be sufficient statistical information obtained or sufficient time accumulated.
Paragraph 11.0	Preparation of Testing Data
	MIT/DL concurs with the provisions of this paragraph.
Paragraph 12.0	Limited Life Program
	MIT/DL concurs with the provision of this paragraph.
Paragraph 13.0	Parts and Materials Program
	MIT/DL concurs with the provisions of this paragraph.
Paragraph 13.1	NASA Parts and Materials Application Problems
	MIT/DL will comply with the provisions of this paragraph.
Paragraph 13.2	Manned Spacecraft Criteria and Standards
	MIT/DL will comply with the provisions of this paragraph.
Paragraph 13.3	Non-metallic Materials Program
	MIT/DL will comply with the requirements of MSC-PA-D-67-13, category H, where applicable.
Paragraph 13.4	Electrical, Electronic, and Electro-mechanical Parts Program
Paragraph 13.4.1	Parts Program Plan
	MIT/DL will comply with the provisions of this paragraph.
Paragraph 13.4.2	Parts Derating
	MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.3 — Parts Selection and Specification

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.4 — Parts List

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.5 — Parts Qualification

MIT/DL will comply with the provisions of this paragraph. Parts qualification test plans will be submitted to the NASA for review and information. Test activity will commence at the earliest possible time. The approved parts list will define the method and status by which each part is qualified. Test reports will be submitted to NASA.

Paragraph 13.4.6 — Parts Application Reviews

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.7 — Parts Screening Tests

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.8 — Parts Procurement and Screening Laboratories

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.9 — Parts Control Responsibility

The procedure to be followed by MIT/DL for supplier control is contained in QOP-003.

Paragraph 13.4.10 — Parts Traceability

MIT/DL will comply with the provisions of this paragraph.

Paragraph 13.4.11	Parts Failure Reporting, Unsatisfactory Condition Reporting, Analysis and Correction MIT/DL will comply with the provisions of this paragraph. NASA ALERTS will be handled as described in paragraph 13.1 of this review.
Paragraph 13.4.12	Parts Statement of Quality Parts and materials which require special processing will require certificates of compliance or conformance as part of the procurement package. MIT/DL will retain copies of the Certificates of Compliance for the required time period.
Paragraph 13.4.13	EES Parts Definitions MIT/DL will comply with the provisions of this paragraph.
Paragraph 14.0	Reliability Documentation Requirements MIT/DL will comply with the provisions of this paragraph.
Paragraph 14.1	Reliability Progress Reports MIT/DL will comply with the provisions of this paragraph.
Paragraph 14.2	Reliability Documentation Submittal MIT/DL will comply with the provisions of this paragraph.

4.5 Exhibit A, Appendix III.

1.1 Due to the criticality of the delivery schedule, items may be released for manufacture as drawings become available rather than waiting for a complete drawing package suitable for the critical design review. The contractor will provide traceability and configuration control of items fabricated before the critical design review is held.

1.2 No comment.

2.0 No comment.

3.0 No comment.

4.6 System Safety Requirements

Appendix IV System Safety Requirements

1.0 Scope

No comment

2.0 Document

No comment

3.0 Definitions

No comment

4.0 System Safety Plan Requirements

Responsibility for system safety will lie with the appointed R&QA engineer. It will be his function to assure the following safety program elements are adhered to.

- Establishment and maintenance of a file of safety problems and their disposition.
- Awareness of potential safety problems as determined by review of NASA ALERTS.
- Support the review and investigation of MSC identified hazards.
- Review and evaluation of design and any proposed changes in accordance with QOP 002 to assure they do not impact safety requirements.
- Remain cognizant of the affect of interfacing equipment on system safety.

- Review of documentation relating to testing, handling, or transporting, and assessment of potential safety hazards resulting therefrom.
- Investigation and correction of any conditions that are observed which may result in a safety hazard.
- Deviations from prescribed documentation which may have safety implications will be documented in accordance with QOP 007.
- FMEA studies will consider safety aspects as noted in QOP 018.

4.7 Comments on Appendix B (Technical Specification).

1.1 No comment.

1.2 No comment.

1.3 No comment.

1.4.1 No comment.

1.4.2 No comment.

1.4.3 Insert "Compatibility Unit" in place of "Prototype Hardware."

1.4.4 No comment.

1.4.5 Insert "Interface Mockup" in place of "Mass Mockup Hardware."

1.4.6 No comment.

1.4.7 Substitute "Training Mockup" for "Training and Interface Mockups."

1.4.8 No comment.

2.1.3 The GSE specification appears as "MSC-GSE-MFIS-2" and should appear as "MSC-GSE-MFIS-2A."

2.2 No comment.

2.3 No comment.

2.4 No comment.

Appendix B Section 3 (Technical Requirements)

3.1.1.1.1.	First paragraph, third sentence: Add "with the same interface hardware and orientation to "...and the receiver will be capable of transport on either the MET or LRV."
3.1.1.1.1.	Second paragraph, third sentence: Change to: "All SEP equipment shall be contained in two packages which will interface with Quad III."
3.1.1.1.1.	Second paragraph, twelfth sentence add: "except for the possibility of periodic dusting during traverse."
3.1.1.1.1.	Second paragraph, last sentence; Replace this sentence with: "Range and azimuth information will be determined from SEP-recorded data in accordance with Section II of the SEP Conceptual Design Report #CSR-TR-70-7.
3.1.1.2	Change "and remaining on the moon in a non-operative status for a period of one week without failure" to "and remaining on the moon in a non-operative status in the equipment bay for a period of 3 days, or on the surface of the moon in a standby status for a period of 3 days without failure." Change "10 continuous hours" to "9 continuous hours."
3.1.1.3	No comment.
3.1.1.4	No comment.
3.1.1.5	No comment.
3.1.1.5.1	No comment.
3.1.2.1.	The SEP transmitter will conform to the general layout of figure 3. Details, such as location of handles, will

be different than shown.

3.1.2.1.1. Change to:
"Size : the transmitter shall not protrude beyond a rectangular envelope size of 10" x 10.5" x 11"."

3.1.3.1.2. Change to:
"Weight - the maximum weight allowed for the transmitter shall be 15 pounds."

3.1.2.1.3. The output power will be sufficient to give the specified range only at the lowest frequency.

3.1.2.1.4. No comment.

3.1.2.1.5. No comment.

3.1.2.1.6. The transmitter shall have a power switch for the following operations:
(1) off, (2) standby, and (3) on.

3.1.2.1.7. The transmitter shall be capable of continuous operation on the lunar surface during all traverses when the SEP experiment is being conducted.

3.1.2.2. The transmitter antenna shall consist of four multiple-conductor strips which constitute the radiating elements.

3.1.2.3.1. Change to:
"Size - the receiver shall not protrude beyond a rectangular envelope of 10x13x11 inches in the stowed configuration except for the loop antennas which may protrude into the transmitter volume."

3.1.2.3.2. Change to:
"Weight - the weight of the receiver including the tape recorder shall not exceed 15.0 pounds."

3.1.2.3.3. Change to:
"Sensitivity - The receiver sensitivity shall be such

that an input signal of -130 dBm will produce a recorder-output frequency deviation of greater than 1 Hz.

3.1.2.3.4.	No comment.
Figure 6.	The receiver will conform to the general layout shown in figure 6. Details such as the shape of the loops and the location of switches will be different. Remove "Transmitter stows here."
3.1.2.3.5.	No comment.
3.1.2.3.6.	No comment.
3.1.2.3.7.	No comment.
3.1.2.3.8.	Change "Binary mode switch operation should be employed for the activation of the receiver" to "Receiver activation controls shall be operable by an astronaut on the lunar surface and positive indication of the operating mode shall be given to the astronaut." Change "..on any of the eight frequencies" to ... on one of the eight frequencies."
3.1.2.3.9.	Once the SEP instrument has been activated no astronaut attention will be required until the end of the traverse unless dust conditions require that the radiator be dusted.
3.1.2.3.10.	Change "and/or replacement" to "and."
3.1.2.3.11.	The antenna system shall consist of three orthogonal loop antennas as shown in figure 6a with circular rather than rectangular loops.
3.1.2.4.	Add: "An existing tape recorder that will survive the lunar environment may be used without an additional enclosure."

3.1.2.4.1. No comment.

3.1.2.4.2. No comment.

3.1.2.4.3. The recording time will be a minimum of 9 hours after functional test. The operational temperature extremes will be $0^{o}F$ to $160^{o}F$ ambient with a heat sink temperature of $35^{o}F$ to $135^{o}F$. The recorder will be flight-qualified and will operate reliably in the lunar environment, but Life and Survival probability are not measurable within the scope of this program and will not be specified.

3.1.2.5. Replace with:
"Range and azimuth information will be determined from SEP-recorded data in accordance with Section II of the SEP Conceptual Design Report #CSR-TR-70-7.

3.1.2.5.1. Add:
"using estimated values for lunar parameters that affect achievable range."

3.1.3.5.2. Change to:
"Reduced range and azimuth information shall provide accuracy of ±5% of actual range within 10 wavelengths of the source and ±10% beyond 10 wavelengths. Azimuth angle shall be determined within an accuracy of $\pm 5^{o}$ in the absence of major lateral reflections.

3.1.2.6. No comment.

3.1.2.7.1. Item c. Change "separate package and set up transmitter" to "set up transmitter."

3.1.2.7.2. No comment.

3.1.2.7.3. No comment.

3.1.3.1. Item b. 6. Facilities for reproducing tapes will be provided by the Tape Processing Equipment (TPE) and the system-test GSE will provide capability for functional test of the tape recorder. Change item b. 6 to read: "provide facilities for functional test of the tape recorder."

3.1.3.2. No comment

3.1.3.3.	No comment.
3.1.4.1.1.	a. Change to: The transmitter package dimensions shall be no more than 10 inches by 10.5 inches by 11 inches. b. Change to: The receiver package dimensions shall be no more than 10 inches by 13 inches by 11 inches in the stowed configuration except that the loops may protrude into the volume alotted for the transmitter. c. Change to: The dimensions of stowed configuration of the complete package shall not exceed 20 inches by 13 inches by 11 inches.
3.1.4.1.2.	No comment.
3.1.4.1.3.	No comment.
3.1.4.2.	No comment.
3.1.4.3.	No comment.
3.1.4.4.	Add: Battery packages may be replaced or recharged and tapes and tape recorders may be replaced before launch to satisfy the requirements of this section.
3.1.4.5.	No comment.
3.1.4.6.	No comment.
3.1.4.7.	No comment.
3.1.4.8.	No comment.
3.1.4.9.	No comment.
3.1.5.1.1.	The SEP will be transported to the moon aboard the LM vehicle in Quad III of the descent stage.
3.1.5.2.1.	Add: "with the same interface hardware."

3.2 The SEP flight-hardware-supporting GSE will be designed to MSC-GSE-MEIS-2A, Class II. The Tape Processing Equipment will be designed to MSC-GSE-MEIS-2A Class III.

4.0

Certification test specifications will be prepared in accordance with the requirements of this section and section 5.2.20a of Exhibit A. These documents will be prepared for the deliverable SEP flight instruments and for the SEP GSE.

4.1 No Comment

4.2 No Comment

4.3.1.1.1.g. The Qualification Test procedure requirements will contain recycling and retest requirements in the event of failure during qualification; this will be done to assure minimal delays should a foreseeable failure occur. Should a failure of an unforseen type occur, NASA approval of any new recycling and retest requirements must be available in less than five days to prevent impact on the schedule.

4.3.1.1.1.k. A failure occurring under overstress or off-limit conditions shall not necessarily be construed to be a failure of the qualification test.

4.3.1.1.2.3. The SEP instrument contains significant amounts of insulation and thermal capacity. The temperature of the test article shall be assumed stable when the temperature of the surface of the instrument has stabilized.

4.3.1.1.2.4. See comments on 4.3.1.1.2.3 above.

4.3.1.1.2.5. No comment

4.3.1.1.2.6 No comment

4.3.1.1.2.7. Not applicable

4.3.1.1.2.8. No Comment

4.3.1.1.2.9. No Comment

4.3.1.1.2.10. No Comment

4.3.1.1.2.12. No Comment

4.3.1.1.2.13. The SEP instrument will not be operated in an oxygen environment, so this test is not applicable.

4.3.2.e. The Acceptance Test procedure will contain recycling and retest requirements in the event of failure during acceptance; this will be done to assure minimal delays should a foreseeable failure occur. Should a failure of an unforseen type occur, NASA approval of any new recycling and retest requirements must be available in less than five days to prevent impact on the schedule.

4.3.4. Not Applicable

4.3.5 Not Applicable

5.0 ORGANIZATION

A chart illustrating the interfaces between NASA/MSC, the Principal Investigator, the MIT Center for Space Research, the C.S. Draper Laboratory division of MIT, and Raytheon Company appears in Figure 5-1.

The Principal Investigator is responsible for establishing scientific goals for the experiment, supporting the experiment design, and for establishing and supporting data reduction and processing requirements. The PI is supported in these areas by the MIT/CSR Laboratory for Space Experiments; specific responsibilities include the investigation, through analysis and tests, of experiment variables as they affect the science, and monitoring of the design, engineering and fabrication of the instrument hardware.

The C.S. Draper Laboratory with Raytheon Company as subcontractor is responsible for performing the tasks necessary to design, develop, fabricate, test, and deliver a flight-qualified Surface Electrical Properties Experiment including associated hardware and documentation.

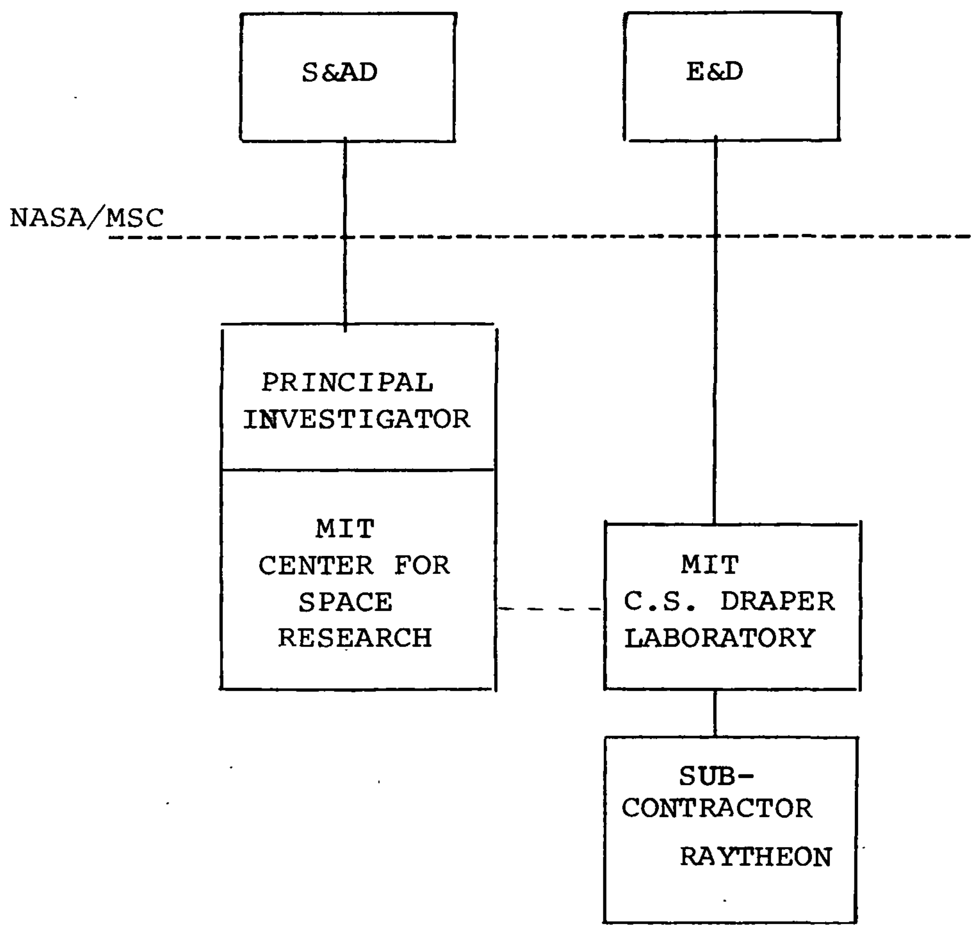

S&AD
E&D
NASA/MSC
PRINCIPAL INVESTIGATOR
MIT CENTER FOR SPACE RESEARCH
MIT C.S. DRAPER LABORATORY
SUB-CONTRACTOR
RAYTHEON

Fig. 5-1.

5.1 MIT C.S. DRAPER LABORATORY ORGANIZATION

The Draper Laboratory Organization for the Surface Electrical Properties Experiment appears in Fig. 5-2. Specific responsibilities within the organization are detailed below.

Project Director (J. McKenna). Responsible for overall direction of the SEP program within Draper Laboratory and for coordination of activities with the subcontractor and NASA/MSC.

Administration (M. Murley). Responsible for documentation, cost, and configuration control.

Project R&QA (W. Beaton). Responsible for overseeing the Reliability and Quality Assurance activities for the SEP program.

Electrical Engineering (J. Barker). Responsible for the electrical and electronic design of the SEP hardware and GSE, acceptance and qualification testing, and field-test and mission support.

Mechanical and Thermal Engineering (J. Martin). Responsible for the mechanical and thermal design of the SEP instrument packages, the design verification tests thereof, and for the fabrication of the structural/thermal models, the interface and training mockups, and the engineering prototype.

Human Factors (J. Nevins). Responsible for human factors aspects of the SEP equipment, for the astronaut interface, and for astronaut training activities.

Interfaces (W. Stameris). Responsible for negotiating and documenting interfaces for the SEP equipment with MSC and the spacecraft contractors.

System Engineering (L.B. Johnson). Responsible for system and RF system aspects of the SEP program as they affect the engineering, the design, the fabrication, and operation.

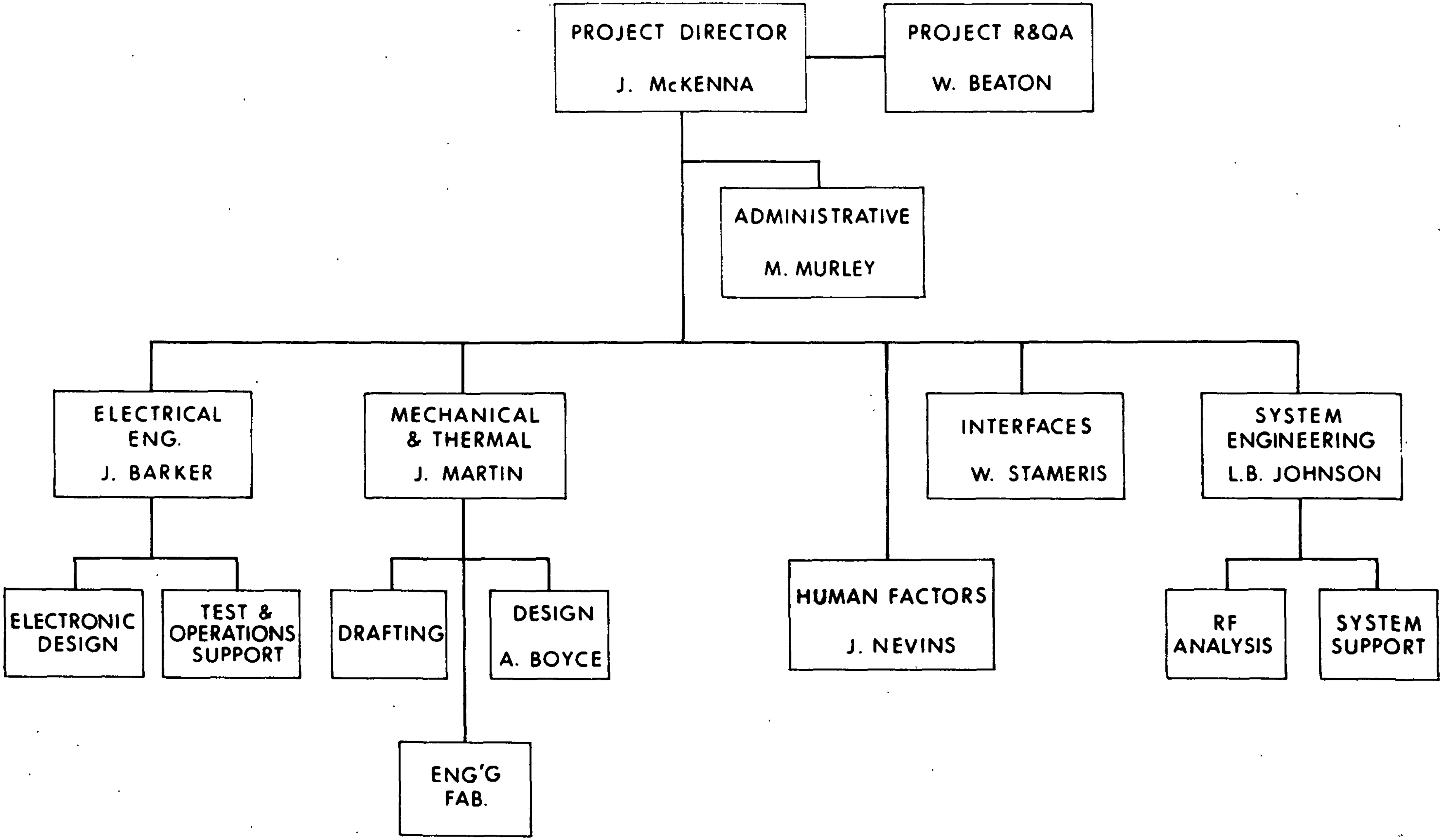


Fig. 5-2. Surface Electrical Properties Experiment Draper Laboratory Project Organization

5.2 IDENTIFICATION OF KEY PERSONNEL

Name	*Present Title*	Project *Responsibility*	*% of Time*
J.F. McKenna, Jr.	Group Leader	Project Dir.	100%
M.G. Murley	Staff Engr.	Administration	100%
G.W. Mayo	Deputy Assoc. Director	CSDL R&QA	10%
W.J. Beaton	Staff Engr.	Project R&QA	50%
J.H. Barker	Assistant Dir.	Electrical Engr.	50%
R.E. Cushing	Group Leader	Electronic Design	100%
J.H. Martin	Group Leader	Mech. & Thermal Engineering	100%
A.J. Boyce	Deput Assoc. Director	CSDL	50%
J. Nevins	Deputy Assoc. Director	Human Factors	10%
R. Schulte	Staff Engr.	SEP Human Factors	50%
W. Stameris	Principal Engr.	Interfaces	50%
L.B. Johnson	Assistant Dir.	System Engineering	90%

John F. McKenna, Jr.

Project Director for Draper Laboratory's Surface Electrical Properties Experiment effort since May 1970. Prior to that he was responsible for Task 3 (Regional Data Bus) of the MIT Space Shuttle Avionics Development Support; Project Engineer and Principal Investigator for the JPL-STAR Read-Only Memory; Project Engineer for the Braid Memory development effort and SIMFAM test memory; responsible for the electronic design of the IL DSKY, the Rotational Hand-Controller Interface Circuitry of the Apollo Guidance Computer, and the clock and digital-to-analog conversion circuitry in the SIRU computer. He has also been responsible for the design of telemetry and data collection apparatus for bio-medical and oceanographic research. He has a B.S.E.E. from Tufts University.

Melvin G. Murley

Bachelor of Science degree in Business Administration Boston University, Master's degree in Business Administration, University of Michigan. Six years of experience in management phases of Apollo program at M.I.T. Mr. Murley has management and supervisory experience in aerospace defense systems design, missiles and jet engine manufacture, with Lincoln Laboratory of MIT, the MITRE Corporation, Raytheon Missiles System Division, and General Electric Company. He is treasurer of the B. Graff Corporation, Windsor Locks, Connecticut.

George W. Mayo

Deputy Associate Director of C.S. Draper Laboratory. Responsible for the establishment, management and implementation of reliability and quality control disciplines within the Draper Laboratory and as required of suppliers and supporting industrical contractors. Major efforts lately have been devoted to supporting the development programs on guidance and control systems for Polaris, Apollo, DSS, and OAO. He is a graduate engineer holding a B.S. in Mechanical and Electrical Engineering from the U.S. Naval Academy in 1945 and has completed postgraduate courses in Instrumentation at MIT, as well as one year of law school at the University of Maryland. He served with distinction in the U.S. Navy as a submarine officer qualified for command and joined the Laboratory in August of 1949 as a Staff Engineer involved in gyro and fire control development and testing. In December 1950 he joined the F.B.I. as a special agent and served in the electronics section of the F.B.I. Laboratory until July 1960 when he returned to M.I.T.

William J. Beaton

BSBA in Engineering Management, Northeastern University 1961.

Reliability engineering: Reliability analysis and modeling, reliability program establishment and monitoring for major space and missile programs, including reliability data collection and retrieval systems; technical liaison between MIT/DL and associate contractors; including on-site residence; responsibility for preparing and implementing quality control programs.

MIT Draper Laboratory, Cambridge, Mass. - Reliability Engineer 10 years. General Electric Ordnance Systems, Pittsfield, Mass. - Reliability Engineer 1-1/2 years. MIT Draper Laboratory - Reliability and Quality Assurance Engineer - 2 months.

John H. Barker

John H. Barker received his B.S. degree from Purdue University in 1957. He is the Director of Division 35E, an electronics design and engineering group. He has experience in the development of electronics for Radar Systems, Inertial Navigation Systems (Gimbal & Strapdown), Shaft Angle Encoders and Pulse Rebalanced Loops for Gyros and Accelerometers. He has served as a technical coordinator with responsibility for review and acceptance of manufacturing changes performed on the Apollo Coupling and Data Unit as well as providing flight support and problem analysis for electronics associated anomallies on the Apollo program.

Raymond J. Cushing

Mr. Raymond J. Cushing, prior to joining the staff of Draper Laboratory, had fifteen years experience in the areas of analog circuit design, digital circuit design and servo design; as associated with the fields of analytical, nuclear, and process instrumentation.

His experience while with Draper Laboratory, covering a period of five years, has been analog and digital circuit design, as well as servo design in the area of navigational systems and instrumentation. He has his bachelors degree from Kansas State University and his Masters degree from Northeastern University, both in electrical engineering.

Arthur J. Boyce

Deputy Associate Director of the C.S. Draper Laboratory. In charge of the Mechanical Design Group responsible for the hardware for various NASA and Deep Submergence systems. After receving his B.S. from the University of New Hampshire in 1949 he worked as plant engineer for Wyman-Gordon. In 1956, he took a position in the Nuclear Division of the Martin Company in Baltimore where he worked until he came to the Draper Laboratory with the Mechanical Design Group in 1957. Initially he worked with the Polaris Design Group.

Jacob H. Martin

Received a Bachelor of Science Degree in Mechanical Engineering in 1955 from Cornell University after which he served as a line officer in the U.S. Navy for two years. Upon release from active duty as a Lt. (JG), Mr. Martin returned to Cornell to earn his Master of Science Degree in Thermal Engineering and Engineering Physics. He started work at the Sprague Electric Company in the hybrid circuit laboratory in 1959 and was later made head of this department. After eight years with Sprague he moved to his present position as Group Leader at the MIT Draper Laboratory. His responsibility is in the area of packaging aerospace electronic equipment and mechanical and thermal design. He has written several papers and holds several patents for electronic capacitors and hybrid circuits.

James L. Nevins

Director of Displays and Human Factors Division for the Apollo Project in the Instrumentation Laboratory. He is responsible for the man-machine design for the Apollo Guidance, Navigation and Control System including hardware and software design, related simulations and their design, crew training, and mission-related activities. Since 1966, in association with the M.E. Department he has sponsored thesis and written papers in the areas of teleoperators (remote manipulators) and unmanned planet rovers. Dating from the same period in association with the M.E. Department and MGH he has also been active in organizing possible support systems for telediagnosis (remote diagnosis via TV). He joined the Instrumentation Lab in 1952 as a test engineer in the Inertial Gyro Group. Before receiving his B.S.E.E. from Northeastern University, in 1952, he was employed in the same group as a student on the Cooperative plan and saw service in the U.S. Army Signal Corps. Since 1952, he has had various responsibilities in the Gyro Research Group, the Analytical Group, and the PACE Group. In 1956 he received his M.S. from MIT in the Department of Aeronautics.

Roger E. Schulte

Prior to joining the MIT Draper Laboratory staff, he had ten years experience in the Design and Testing of Spacecraft Scientific Packages for Venus Probe, OAO, and related fields. He has special experience in the design of photometers, optical, radar and IR trackers, a solar radiation simulator, stable platforms, and servo mechanisms.

In his six years with Draper Laboratory, he has supported the Apollo program in the specification and testing of cockpit displays, design co-ordination and Apollo mission testing. He has also been active in the environmental testing of the Apollo space sextant/telescope, navigation base, and display and control panels.

William A. Stameris

Participated in the design of the Apollo guidance system. General responsibilities involved overall system considerations of design, integration, and configuration control. Contributions and responsibilities included: a) Established the grounding, shielding, power and signal distribution and wiring philosophy for the G&N system; b) Specified and layed out the wiring of the IMU; c) Responsible for technical negotiation and approval of all MIT interface control documentation with North American, Grumman, NASA, and International Latex Corporation; d) Acting chairman of the Design Review Board. Review and approve all Class A initial release and Class 1 changes to the G&N airborne and GSE hardware; e) Member of the Change Control Board; f) Was a member of the EMI(electromagnetic interference) control panel; g) Was vice chairman of an MIT committee which made an in-depth study of the G&N system with regard to potential fire hazards. Mr. Stameris has also participated in the design of the Gunfire Control System X-1, the Polaris Missile Guidance System, and the MK80 and MK84 fire control systems.

Leonard B. Johnson

Mr. Johnson received a BSEE degree from MIT and a BA degree from Bowdoin College in 1947. He completed graduate courses in EE at MIT (1948-1952) and received a certificate from the Management Development Institute in 1961. Mr. Johnson joined the Draper Laboratory in 1963 as director of the Apollo Guidance and Navigation Radar Group. In this capacity, Mr. Johnson provided technical direction of the radar group in the definition and integration of the Apollo radars with the Apollo Guidance and Navigation System. This effort included definition of radar requirements for support of the guidance and navigation function, specification of the radars, definition and specification of the radar-guidance interface both for hardware and software, technical monitoring of the radar development, definition and monitoring of flight tests, definition and conduct of interface tests to verify both the hardware and software performance of the radars and the radar-interface in integrated configuration, support of ground checkout, pre-launch support,mission support, and post flight analysis of telemetry data to assess the performance of the radar and radar interfaces. Mr. Johnson continues to direct the CSDL radar effort in support of future Apollo missions and Skylab activity. He is also currently leader of the Navigation Radiation Sensor Coordination Group for the NASA Space Shuttle Vehicle activity at CSDL which is concerned with the development of navigation sensor concepts and devices, the sensor interfaces and the integration of the radiation sensor subsystems with the guidance and navigation system and with the data management system of the Reusable Space Shuttle Avionics system. Prior to joining CSDL, Mr. Johnson spent 10 years with the Dunn Engineering Corporation, first as Chief Engineer and later as Director of Technical Operations. In this role, he was responsible for initiation and technical direction of a variety of programs including engineering improvements of the Talos missile electronic guidance system, development of automatic production test equipment for both Sparrow and Hawk missiles, and development of precision inertial test systems including the first inherently compensated air bearing gyro test turntables. From 1947 to 1955, Mr. Johnson was a staff engineer of the MIT Research Laboratory of Electronics, performing research and development for the electronic homing guidance system of the Meteor missile. In this connection, he engaged in the development of toroidal coils, an airborne spectrum analyzer, L-band antenna design and an experimental X-band CW radar system, and is co-holder of a patent on the design of an electronic homing seeker.

6.0 TASK DESCRIPTIONS AND MAN LOADING

6.1 TASK DESCRIPTIONS

This section describes the activities represented by the seventeen tasks called out in the work-breakdown structure and Draper Laboratory's proposed effort under each task. The subcontractor's effort under each task is described in Volume I of Appendix III to this proposal.

6.1.1 Task Ia. Program Management

This task contains the activities required for management of the SEP program, including monitoring and controlling program progress, schedules, and cost as well as configuration and documentation control.

Overall program management responsibility rests with the Draper Laboratory. The management of the subcontractor's activities are described in Section 13.2 of Volume I of Appendix III.

6.1.2. Task Ib. Reliability and Quality Assurance

This includes all aspects of the Reliability and Quality Assurance activity for the SEP program except for the R&QA portion devoted clearly to documentation which is in Section XII. This task covers the generation and implementation of R&QA plans and procedures, parts qualification, vendor surveys and inspection, vendor and subcontractor acceptance test monitoring, and in-process inspection, FMEA, and parts and materials evaluation.

The subcontractor will be responsible for in-line process inspection, acceptance test monitoring, and maintaining failure history. See Appendix III Section 13.3 . CSDL is responsible for all other aspects of the R&QA program as well as the monitoring of the subcontractor R&QA effort. CSDL will use engineering resident support for some of their R&QA activity.

6.1.3 <u>Task II. Interface Control</u>

This task covers a.) the activities required for negotiating and documenting interfaces between the SEP instrument hardware and the various vehicles (LM, CM, MET, LRV); and b.) the various activites included in human factors analysis, astronaut training, and the astronaut interface. Pure documentation activities (drafting and publication) involved with these efforts are covered under tasks IIIb and XII. This task is to be accomplished completely by CSDL.

6.1.4 <u>Task IIIa. Conceptual Design, Electrical</u>

Tasks IIIa and Task IIIb cover the complete design, design verification and specification of the flight instrument package in preparation for a design release to the subcontractor for producibility review and manufacturing. Resident support and an independent design review provided by the subcontractor will expedite the design and the transfer of those requirements to the subcontractor's manufacturing tasks described in Appendix III.

The analysis and testing of the articles produced under Tasks IV, V, and VI are required for the design verification activities conducted under this task.

Task IIIa covers the activities required for accomplishing the systems and electronic design and analysis of the SEP instrument hardware; for the initiation of specifications; for construction of the field evaluation model (breadboard); for support of the field trails of the field evaluation and prototype models; and for fabrication of the EMI receiver electronics. Drafting and documentation costs for this activity are included under Tasks IIIb and XII.

The conceptual design task with the exception of the antennas will be accomplished by CSDL using resident engineering support provided by the subcontractor. The subcontractor's responsibility for the antenna design and engineering support is covered in Appendix III, Section 13.4 .

6.1.5 Task IIIb. Conceptual Design, Mechanical

This task covers the activities of structural and thermal design of the SEP instrument, the fabrication and test of structural/thermal models, the design and fabrication of mechanical components for the EMI test receiver, the support of the structural and thermal designs throughout fabrication and the mechanical design of the complete flight transmitter and receiver. Engineering drafting, electronic as well as mechanical, is included here.

The conceptual design task with the exception of the antennas will be accomplished by CSDL using resident engineering support provided by the subcontractor. The subcontractor's responsibility for the antenna design and engineering support is covered in Appendix III, Section 13.5 .

6.1.6 Task IV. Interface Mockup

This task covers the activities associated with the fabrication of the interface mockup and the engineering and drafting attributed solely to it given a flight equipment design under IIIb above. Where possible, parts procured to the flight design will be used. The fabrication assembly and test of this mockup is to be accomplished by CSDL.

6.1.7 Task V. Training Mockup

This task covers the activities associated with the fabrication of the Training Mockup and the engineering attributable directly thereto given a flight equipment design under IIIb above. Where possible parts procured to the flight design will be used in preference to the design and procurement of special parts for the model. The fabrication assembly and test of this mockup will be accomplished by CSDL.

6.1.8 Task VI. Prototype

This task includes the activities associated only with the fabrication of the engineering prototype of the SEP instrument and the engineering attributable directly to it given a flight design under IIIa and IIIb above. Where possible, components and parts procured to the flight design will be used rather than specially designed and fabricated parts. No production controls are required on this item, and the recorder to be used is assumed to be GFE

With the exception of the antenna, which will be supplied by the subcontractor, CSDL will do the fabrication, assembly, integration, and test of the complete instrument.

6.1.9 Task VII. Fabrication, Compatibility Unit

This task covers the activities and man-loading directly attributable to the fabrication, in-process test, integration, functional test, acceptance test, and sell-off of the Compatibility Unit. R&QA support is included under Task Ib; and general fabrication costs (facilities, management, engineering, etc.) are included under Task XV. Abbreviated pre-qualification tests are included under Task IX. This unit will be built with as many actual flight components as possible with substitutions as necessary to meet the schedule.

This task is to be accomplished by the subcontractor, with CSDL monitoring the R&QA operation and procuring the tape recorder and solar panel. For the subcontractor effort, see Section 13.7 of Appendix III.

6.1.10 Task VIII. Fabrication, Qualification Unit

This task covers the activities and man-loading directly attributable to the fabrication, in-process test, integration, functional test, acceptance test, and sell-off of the Qualification Unit. R&QA and support is included under Task Ib; and general fabrication costs (facilities, management, engineering, etc.) are included under Task XV. Qualification tests are included in Task IX. The qualification unit is built completely with flight qualified components and is representative of all flight-qualified units. This task will be accomplished by the subcontractor with CSDL monitoring the R&QA operation and procuring the tape recorder and solar panel. For the subcontractor effort see Section 13.8 of Appendix III.

6.1.11 Task IX. Qualification Testing

This task includes generation of the Qualification Test Specification (QTS), the Qualification Test Procedure, performance of the Qualification Test, and preparation of the Qualification Test Report. Prequalification tests on the Compatibility Unit are also done under this task. Routine documentation (drafting and publication support) is done under Task XII.

CSDL will prepare the QTS, review the qualification test procedure and report, and monitor qualification and pre-qualification testing. The subcontractor will prepare the Qualification Test Procedure and report, will design and fabricate the necessary test fixtures, and will conduct the qualification and pre-qualification tests; see Section 13.9 of Appendix III.

6.1.12 Task X. Fabrication , Flight Units

This task covers the activities and man-loading directly attributable to the fabrication, in-process test, integration, functional test, acceptance test, and sell-off of two Flight Units and the portion of the flight hardware materials required for them. R&QA support is included under Task Ib; and general fabrication costs (facilities, management, engineering, etc.) are included under Task XV.

This task will be accomplished by the subcontractor, with CSDL monitoring the R&QA operation and procuring the tape recorders and solar panels. For the subcontractor effort, see Section 13.10 of Appendix III.

6.1.13 Task XI. Ground Support Equipment

This task covers design, documentation, and fabrication associated with the three sets of GSE used for system-level test of the SEP hardware. The tape processing equipment is accounted for separately under the PI support section. Task XI includes the electrical and mechanical design of the SEP GSE, procurement of equipment and component, fabrication, in-process test, functional test, and acceptance test.

This task will be accomplished by the subcontractor, with CSDL monitoring, and performing design review. See Section 13.11 of Appendix III.

6.1.14 Task XII. Documentation

This task covers the writing of specifications (other than those listed elsewhere in this section), training and operation manuals, routine documentation associated with R&QA, and the cost of drafting other than that inherent to Task IIb such as processing changes following release to the subcontractor for manufacturing. Materials under Task XII include Photography Laboratory Support, Publication Support, overall print room costs for batch reproduction, drafting supplies, and computer time for documentation and configuration control.

Activities under this task are done by CSDL with resident support provided by the subcontractor; the subcontractor's efforts under this task are described in Section 13.12 of Appendix III.

6.1.15 Task XIII. PI Support

This task includes the activities required under Exhibit C, Principal Investigator's Statement of Work. These activities are described in Volume I of the PI and science proposal.

6.1.16 Task XIV. Operation Support

This task includes the activity and travel to establish and conduct flight hardware and mission support for the SEP instrument at NASA/KSC. Initial installation of the GSE equipment at KSC is contained here.

This task is to be accomplished by CSDL with support from the subcontractor as described in Section 13.13 of Appendix III.

6.1.17 Task XV. Fabrication

This task includes all activities associated with flight-hardware fabrication that are not directly attributable to the fabrication of any of the four flight-configured units. This task includes fabrication management, producibility review and liaison activities, and in-process test equipment design and fabrication.

This task is to be accomplished by the subcontractor; see Section 13.14 of Appendix III.

6.2 *MAN LOADING*

Table 6-1 illustrates Draper Laboratory's effort against each task listed in 6.1 by month.

APPENDIX 7.2

M.I.T. CENTER FOR SPACE RESEARCH

TECHNICAL PROPOSAL FOR THE

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

JANUARY, 1971

M.I.T.

CENTER FOR SPACE RESEARCH

CAMBRIDGE, MASSACHUSETTS

PROPOSAL TO NASA

MANNED SPACECRAFT CENTER

IN RESPONSE TO

REQUEST FOR PROPOSAL

JC931-88-1-165P

VOLUME I

TECHNICAL PROPOSAL FOR THE SURFACE ELECTRICAL PROPERTIES EXPERIMENT

JANUARY 1971 *

*. REPLACES PREVIOUS PROPOSALS SUBMITTED UNDER JC931-88-1-165P

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

TECHNICAL PROPOSAL

CONTENTS

1.0 INTRODUCTION

This document is a preliminary technical proposal by the MIT Center for Space Research to the NASA Manned Space Center in response to MSC RFP JC 931-88-1-165P, dated Oct.   1970. CSR proposes to provide all personnel, equipment, facilities, special test equipment, travel and materials (unless specified elsewhere to be GFE) necessary to define, design, develop, fabricate, test and deliver a flight-qualified Surface Electrical Properties Experiment, including associated hardware   and documentation, and to provide equipment and effort for some reduction and analysis of Experiment data, as described in Volume I of this proposal.

This technical proposal is preliminary because it is submitted to MSC in advance of evaluation of responses by solicited industrial bidders to a CSR RFP for the design, development, fabrication, test and delivery of flight-qualified SEP Experiment hardware and associated documentation by means of subcontract. Details of this preliminary proposal are subject to revision by CSR following or simultaneous with CSR negotiation of a subcontract with the selected industrial bidder to ensure compatibility between what is required by CSR from the subcontractor and what is proposed by CSR to the MSC.

2.0 FACILITIES

The Center for Space Research is a multidisciplinary research center engaged in a broad program of sponsored research in the space sciences and engineering. The faculty investigators in charge of this program are drawn from several disciplines and departments of the Institute. Experimental and theoretical studies are under way on cosmic rays, interplanetary plasmas, solar physics, and other astrophysical phenomena; life support in unusual environments, multiple loop control characteristics of the human operator and biophysical evaluation of the human vestibular system; interplanetary guidance and navigation of space vehicles, advanced geodetic applications and missions and space trajectory analysis; space propulsion and power generation and the fluid dynamics of gaseous nuclear rockets; studies of the ground states of rare gas-solid surfaces; studies of the spectral reflectivity of planetary surfaces and properties of the Martian atmosphere; experiments on the prebiotic synthesis of polynucleotides and detection of biological systems on Mars; laboratory studies of neuroendocrine rhythms and protein and amino acid requirements in humans.

Experimental techniques employed in the foregoing study areas include the usual laboratory research methods and procedures, as well as the conducting of field measurements from payloads carried aboard high altitude balloons, sounding rockets, satellites and space vehicles. Extensive computation facilities are avialable for analysis and reduction of scientific data. An experienced and well-equipped laboratory group for the design, construction and testing of space payloads is an integral part of the Center. Thus the Center affords the opportunity for the integration and coordination of the varied science and engineering arts associated with these investigations and equipment development while affording students the opportunities for part-time work and thesis study.

3.0 ORGANIZATION AND RESPONSIBILITIES

The MIT Center for Space Research has established a SEP Program Management Office to ensure that appropriate equipment is designed, produced, tested, and delivered within the cost and schedule requirements of the contract, to provide the means of conducting a lunar surface electrical properties experiment on the flight of Apollo 17.

This proposal describes a team effort involving the Principal Investigator, MIT departments supporting the program, a hardware subcontractor, and MSC.

The basic organization of the Program Office is indicated in Fig. 3-1. Once the conceptual design and experimental objectives have been arrived at by the Principal Investigator and his engineering support team in LSE, the ongoing responsibility and authority for all decisions and direction of the SEP hardware rests with the Program Manager, J.W. Meyer. Reporting to Dr. Meyer and providing the primary support for exercise of the functions of the office are: R. H. Baker, Head of the CSR Laboratory for Space Experiments and L. B. Johnson, an Assistant Director of the Charles Stark Draper Laboratory. In addition, L. J. Ricardi, Leader of the Antenna and Sites Group of Lincoln Laboratory and J. A. Kong of the MIT EE Department provide special technical staff support in the areas of antenna design and propagation studies respectively.

The functional role of the SEP Program Office is defined in Fig. 3-2, which shows the major activities of the Office as well as the sources of support for these functions.

The Principal Investigator is responsible for establish-

PROGRAM MANAGEMENT OFFICE ADMINISTRATIVE ORGANIZATION

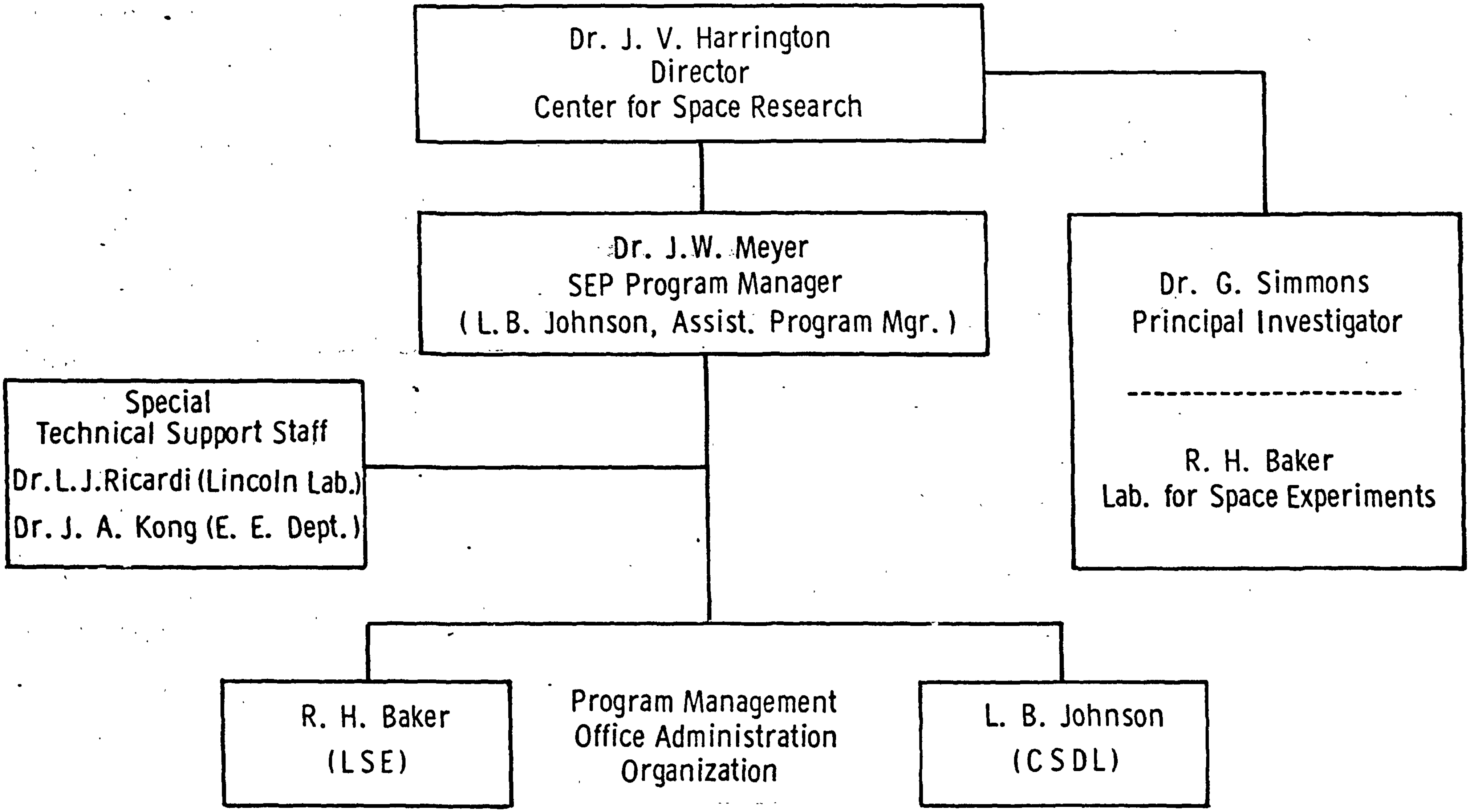


Fig. 3 - 1

SEP PROGRAM MANAGEMENT OFFICE
FUNCTIONAL ORGANIZATION

- PROGRAM MANAGEMENT OFFICE
  - Experiment Definition and Design
    - Experiment Definition — Principal Investigator
    - Analysis and Conceptual Design — LSE
    - Antenna Design — Lincoln Lab
    - Propogation Studies — EE Dept
    - Field Tests — LSE
  - Design Implementation and Subcontractor Management
    - Subcontract Admin.
    - Engineering Support — CSDL
    - Reliability and Qual. Assurance — CSDL
    - Configuration Control and Documentation — CSDL
  - Data Reduction and Analysis
    - Preflight — PI and LSE
    - Postflight — PI and LSE

Fig. 3-2

ing scientific goals for the experiment, supporting the experiment design, and for establishing the supporting data reduction and processing requirements. Unique requirements of the SEP experiment necessitate substantial technical support for the Principal Investigator which is provided primarily by LSE and the Special Technical Support staff. Personnel drawn from the CSDL will be utilized in program management and supervision of the subcontractor. The project management will also draw on personnel from MIT/ Lincoln Laboratory and on the Department of Electrical Engineering for consultation services as required to support program objectives.

In discharging its responsibility, the Project Management will carry out the following tasks:

Coordination and Communication

Coordinate efforts of those concerned with the experiment design, analysis and field tests and with experiment hardware implementation. Facilitate communication among the Principal

Investigator, CSR and its subcontractor, and the MSC. Provide designated necessary documentation and reports; review and approve those written elsewhere. Support meetings, conferences, and resolution of action items as necessary to satisfactory accomplishment of the task.

Design Decision

Resolve conflicting requirements on the basis of the best available data and advice. Assess impact of design decisions on the experiment. Direct the subcontractor for appropriate implementation of design decisions.

Program Control

Exercise administrative program control; i.e. cost, budgets, configuration and procedures control; program coordination; reporting, drawing and document approval and distribution; and subcontractor supervision and administration.

Reliability and Quality Assurance

Assure discharge of contractual R & QA requirements through monitoring and direction of the subcontractor's R & QA program. Major areas of CSR concern will be: Subcontractor R & QA management; design for reliability; parts and materials selection and screening; fabrication and assembly operations; testing; failure reporting and corrective action.

Engineering Support

Provide engineering support that will ensure realization of experiment instrumentation objectives with adequate scientific/engineering interaction and technical monitoring and direction of the subcontractor.

Engineering Support Tasks

1. Design Direction - Translate scientific requirements and objectives to best fit program constraints. Anticipate problems. Devise suitable fall-back alternatives. Direction decisions.

2. Design Monitoring and Review - Monitor and review subcontractor's design of flight hardware and ground support equipment. Perform analyses in support of design reviews. Monitor review critique. Review End Item Specification. Recommend design direction on basis of reviews.

3. Design Verification and Test - Review design verification test plans and test results. Review acceptance test plans and results. Review qualification test plans and results.

4. Conferences - Support: Preliminary and critical design reviews (PDR, CDR); Design Review Board (DRB) meetings; Program reviews, MSC meetings; Configuration Control Board (CCB) meetings; Customer Acceptance Readiness Review (CARR).

SECTION 4

4.0 SEP Hardware Design & Fabrication Description

4.1 Experiment Description

The object of the Surface Electrical Properties Experiment is to determine electrical characteristics of the regolith, to determine layering in the lunar subsurface, and to search for the presence of water at depth. Measurements will be made using radio interferometry techniques.

The apparatus to be used consists of a multifrequency transmitter to be deployed a short distance from the Lunar Module (LM) and a mobile receiver to collect and record field-strength data during traverses away from the LM. The equipment operates at six discrete frequencies from 0.5 to 32 MHz. Block diagrams of the transmitter and receiver conceptual design appear in Figures 4-1 and 4-2 respectively.

4.2 Fabricated Items

4.2.1. Experiment Hardware

The following items of hardware are to be fabricated for the Surface Electrical Properties Experiment.

A. Structural/Thermal Models

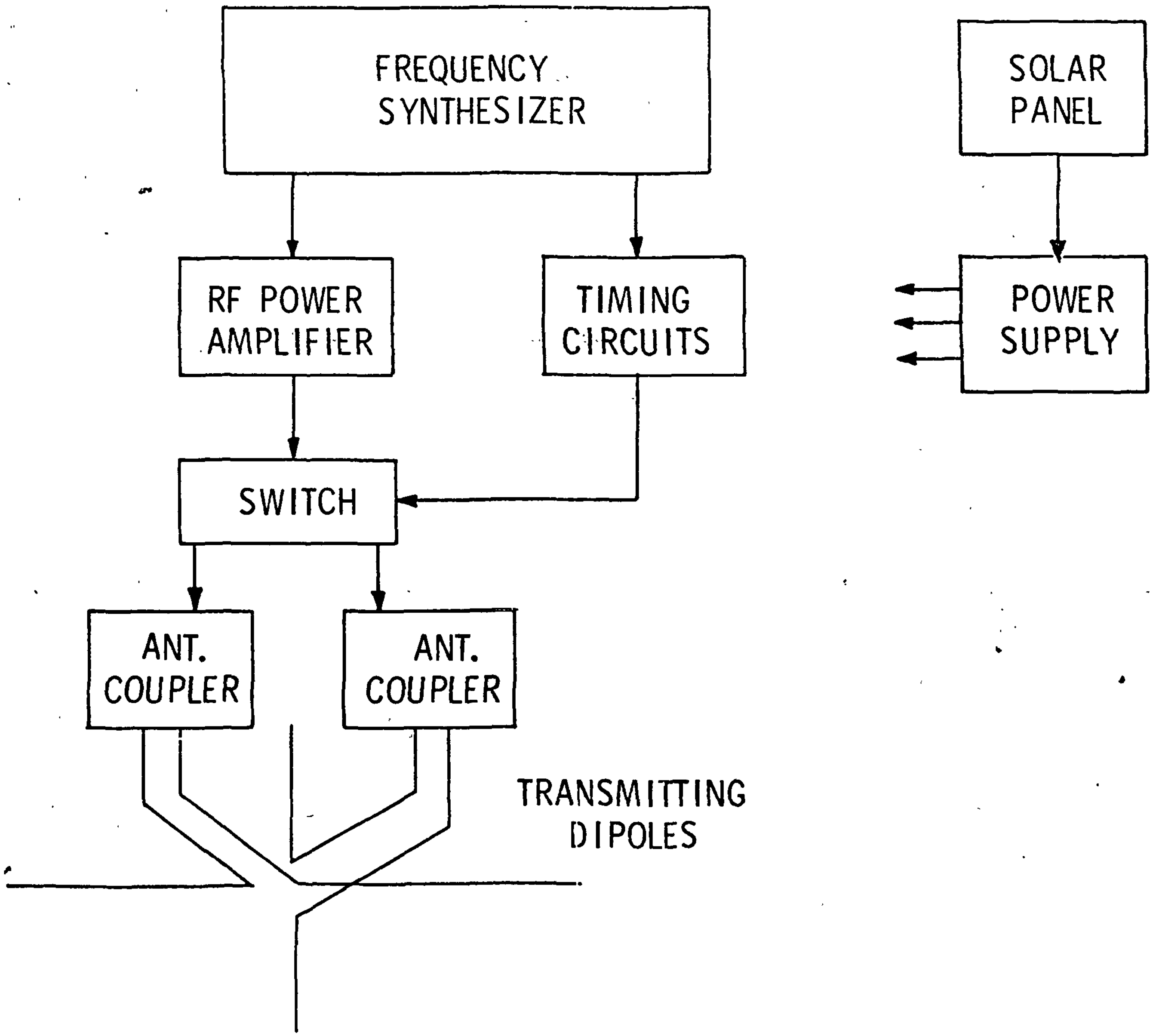
Assemblies built to test the mechanical and thermal design of the SEP hardware. These are to be fabricated by the subcontractor in the course of the structural/thermal design.

B. Field Evaluation Model

An assembly of circuit breadboards into an electrically functional preprototype of the SEP transmitter and receiver and suitably packaged for glacier testing of the SEP experiment and hardware design. This is to be fabricated by the subcontractor and delivered to MIT/CSR for field testing.

Fig. 4-1

SEP TRANSMITTER



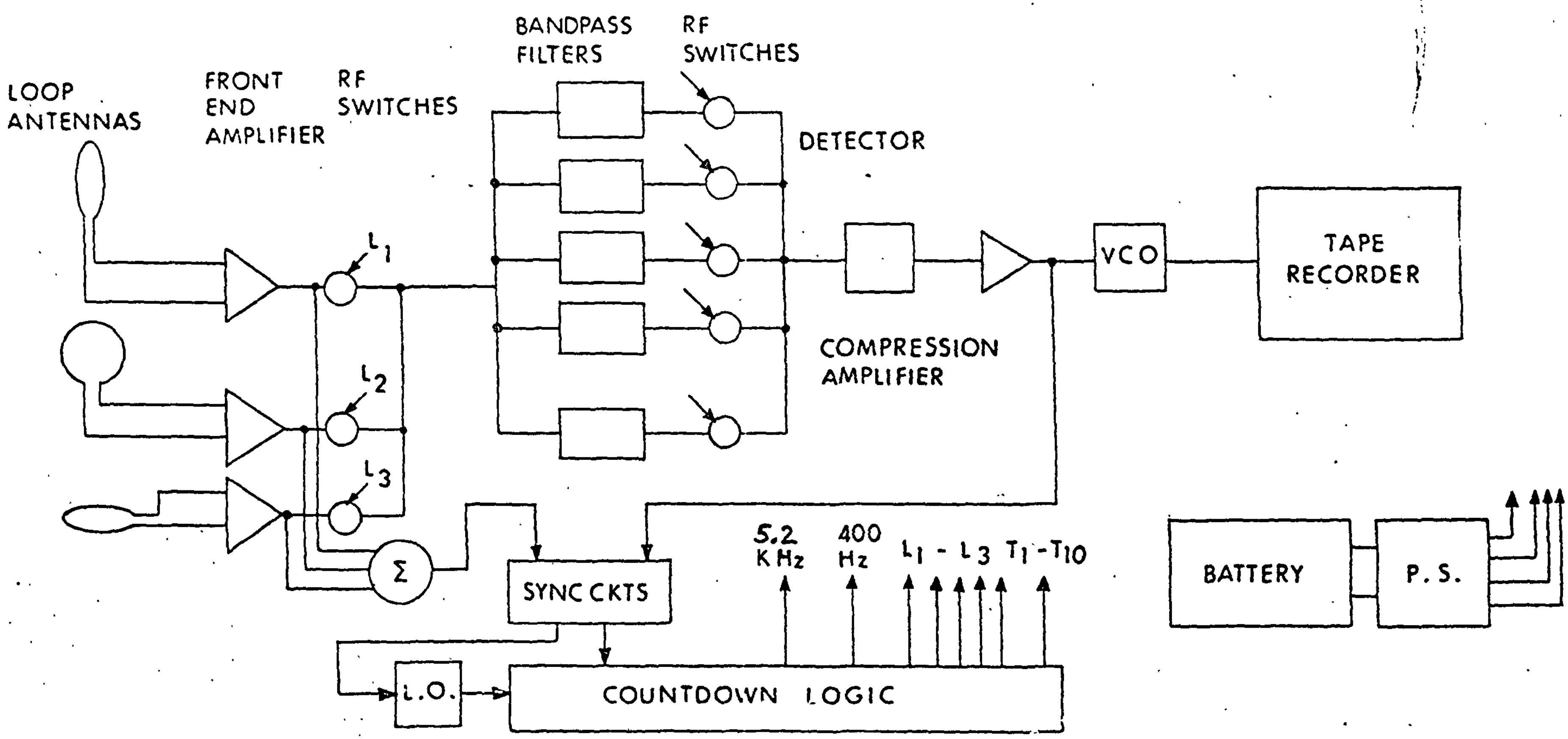


Figure 4-2 SEP Receiver
(Multi-bandpass filter concept)

C. Engineering Prototype

A non-production set of SEP hardware built by the subcontractor for field test of the SEP. This model is to be an imitation of the flight hardware as defined by March 1971.

D. EMI Test Model

A receiver built for the specific purpose of supporting EMI tests of opportunity is being fabricated by MIT/CSDL.

E. Interface Mockup

To verify interfacing and mass properties of the SEP hardware. Contains no electronics and is built by the subcontractor.

F. Training Mockup

A non-functional mockup built by the subcontractor of the SEP hardware for astronaut training. This unit is made as close as possible to simulate 1/6g handling on earth. It contains no electronics.

G. Compatibility Unit

This unis is a production prototype built by the subcontractor to the flight design, and serves to debug production and test procedures; the unit is destined for electromagnetic compatability testing and some pre-qualification tests and is not built completely of flight qualified components.

H. Qualification Model

Built by the subcontractor for qualification testing. This unit is representative of all production units and is the first to contain all flight qualified components.

I. First Flight Unit

J. Second Flight Unit

4.2.2. GSE

The Ground Support Equipment (GSE), to be built by the subcontractor, is designed to run system level tests on the SEP Transmitter and Receiver. The design will maximize the use of commercial test equipment to reduce the number of special circuits which must be designed. Testing will be done without using the antenna to avoid field intensity variations due to antenna spacing and multipath effect.

To reduce cost and schedule, the equipment will be designed for manual operation. This simplified design is envisioned to be satisfactory for the limited scope of the overall program.

The GSE will be fabricated to the requirements of MSC-GSE-Meis-2A Class II.

The GSE proposed does not include facilities for processing, reproducing, or reducing receiver-recorded magnetic tapes. The tape recorders will be procured and accepted by the subcontractor following satisfactorily-completed(and monitored) testing at the vendor's facility. Thereafter, inspection of the recorders may be done with non-elaborate equipment to be contained in the GSE.

4.2.3. Tape Processing Equipment

One set of equipment is required for processing, reproducing, and reducing tapes recorded by the SEP receiver. This hardware item is not necessary for system-level test and will be built by the subcontractor to the requirements of MSC-GSE-MEIS-2A Class III.

The TPE will consist of a reproduce transport rack, two audio recorder/reproducers and a computer-compatible digital tape recorder. Additional panels will contain formatting, conversion, and control circuitry as required.

4.3 Schedule

The SEP program schedule appears in Figure 4-4. Delivery of the major items is as follows:

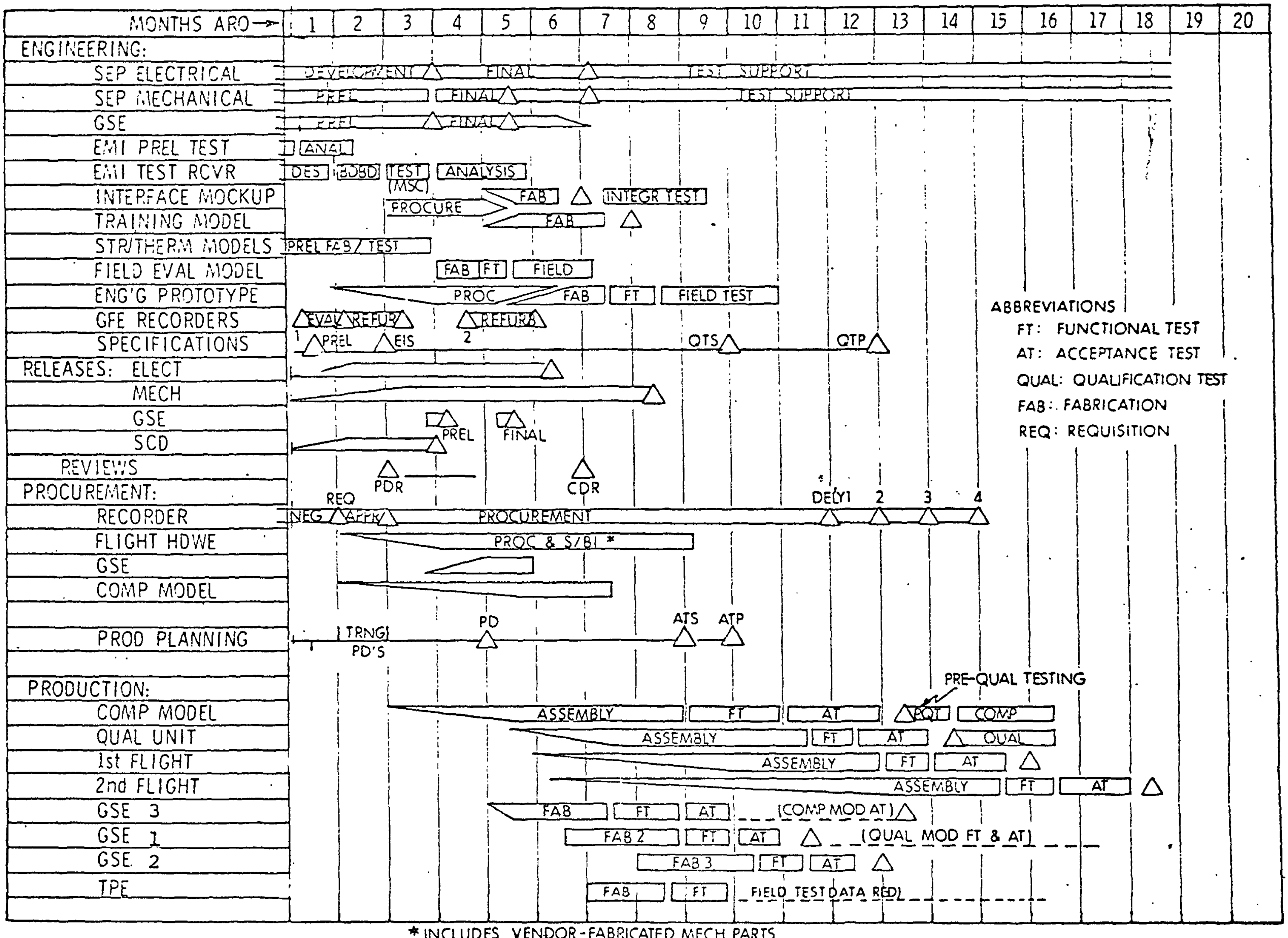
Unit	
Compatibility Model	12.5 months
Qualification Unit	13.5 months
First Flight Unit	15 months
Second Flight Unit	17.5 months
GSE 3	12.5 months
GSE 1	10.5 months
GSE 2	12.0 months
TPE	12.0 months

The first flight unit delivery will occur at the end of April 1972, assuming a funding go-ahead by 1 February 1971.

Procurement of components and hardware will be done as drawings become available. Specification Control Drawings for components will be developed from preliminary parts lists during the early months of the program. The tape

7 4 2.8

SURFACE ELECTRICAL PROPERTIES EXPERIMENT



11-5-70 JFM

Fig. 4-4

4.3 Schedule (con't)

recorder procurement consists of four recorders (one for each flight-configured unit), one GSE (reproduce) rack to operate in conjunction with the Tape Processing Equipment.

The flight hardware procurement cycle shown includes vendor fabricated mechanical components. The fabrication cycles shown include kitting, module assembly, and module-level production test. The functional test cycles include integration, final assembly, and system-level functional test. Fabrication of flight items is started before the Critical Design Review; final assembly takes place after the CDR. Two week periods are alotted after each acceptance test cycle for Customer Acceptance Readiness Reviews.

4.4 Reliability and Quality Assurance

MIT/SCR and the sub-contractor will implement applicable NASA Reliability and Quality requirements as defined in the statement of work. MIT/CSR shall be responsible for establishing, providing direction for, and auditing the sub-contractor's activity.

The manner and method of such implementation shall be contained in the Reliability and Quality Plans to be submitted as required by the statement of work.

4.5 Configuration Management

Configuration management will be implemented as required by the statement of work and as described in CSDL Document E-2509 as applicable. MIT/CSR shall have approval of all Design Review Board and Configuration Control Board actions.

4.6 SEP Fabrication Plan

Fabrication of all items **required** under Article II shall be done by the subcontractor.

4.7 Testing

Testing tasks will be accomplished in accordance with the statement of work. Descriptions will be contained in the subcontractor technical proposal when available, and in the PI and Science Technical Proposal.

SECTION 5 COMMENTS AND EXCEPTIONS TO WORK PACKAGE TASKS

CONTENTS

5.0 MIT accepts the condition of the work package received with RFP JC931-88-1-165P with the following reservations and alternatives. "No comment" indicates that MIT concurs with and/or will comply with the provisions of the specific article or section.

5.1 PROPOSED CONTRACT SCHEDULE

Article I. MIT concurs with the provisions of this article.

Article II.

5. Flight Unit #2 delivery will occur at 17.5 months.

6. Qualification Unit delivery will occur at 13.5 months after receipt of contract.

7. GSE #1 delivery will occur 10.5 months after receipt of contract.

9. GSE #3 delivery will occur 12.5 months after receipt of contract.

Article III - IX.

MIT concurs with the provisions of these articles.

Article X. No comment.

Article XI. No comment.

Article XII - XVI.

No comment.

Article XVII.

See comments below under Exhibit "A", Appendix I and II.

Article XVIII.

See comments below under Exhibit "A", Appendix III.

Article XIX.

No comment.

Article XX.

No comment.

Articles XXI - XXV.

No comment.

Article XXVI. No comment.

Article XXVII. No comment.

Article XIX.

No comment.

Article XX.

No comment.

Articles XXI - XXV.

No comment.

Article XXVI. No comment.

Article XXVII. No comment.

5.2 STATEMENT OF WORK

EXHIBIT A

1.0 No comment.

2.0 No comment.

3.1.a No comment.

3.1.b No comment.

3.1.c See comments under Exhibit A, Appendix I.

3.1.d See comments under Exhibit A, Appendix II.

3.1.e See comments under Exhibit A, Appendix III.

3.1.f See comments under Exhibit A, Appendix IV.

3.1.g No comment.

3.1.h See comments under Section 5.0.

3.1.i No comment.

3.1.j See comments under Section 5.0 and CSDL Document E-2509, "NASA Experiments Configuration Management Plan;" August 1970.

3.2 No comment.

3.3.1 MIT assumes that Table I is the list of equipment contained in Article II. See comments under Article II.

3.3.2 MIT assumes that Table I is the list of equipment contained in Article II. Further, the ground support equipment will be in accordance with MSC-GSE-MEIS-2A Class II, and the Tape Processing Equipment in accordance with Class III.

3.4 No comment.

3.5 No comment.

SECTION 4. Definition d. Add - "The prototype for the SEP experiment is intended for glacier testing of the experiment and hardware design."

SECTION 4. Definition f. Insert - "Interface Mockup" in place of "Mass Mock-Up Hardware."

SECTION 4. Definition g. Insert - "Training Mockup" in place of "High-Fidelity Mock-Up."

SECTION 4. Add definition h. as follows:

h. Compatibility Model - A model equivalent in configuration to the flight hardware that does not contain all flight-qualified components. This unit serves as a production prototype and will be subjected to abbreviated qualification level testing.

Add definition i. as follows:

i. Tape Processing Equipment - One set of equipment is required for processing, reproducing and reducing tapes recorded by the SEP receiver. This hardware item is not necessary for systel-level tests and will be built to the requirements of MSC-GSE-MEIS-2A, Class III. The TPE will consist of a reproduce transport rack, two audio recorder/reproducers and a computer-compatible digital tape recorder. Additional panels will contain formatting, conversion and control circuitry as required.

5.1 No comment.

5.2 No comment.

5.2.1 Change "Clause 69" to Clause 74."

5.2.2 End Item Specifications will be prepared for the flight-configured units, the GSE, and the TPE.

5.2.3 Engineering drawing will be type II so that schedules may be maintained.

5.2.4 See comments under Exhibit A, Appendix I.

5.2.5 No comment.

5.2.6 No comment.

5.2.7 No comment.

5.2.8 No comment.

5.2.9 No comment.

5.2.10 No comment.

5.2.11 See comments under Exhibit A, Appendix II.

5.2.12 See comments under Exhibit A, Appendix IV.

5.2.13 No comment.

5.2.14 No comment.

5.2.15 No comment.

5.2.16 No comment.

5.2.17 No comment.

5.2.18 No comment.

5.2.19

d. Insert "Compatability Unity" in place of "prototype."

5.2.20

b. No comment.

5.2.21 Change "Clause 69" to "Clause 74."

5.2.22 No comment.

5.2.23 No comment.

TABLE II. Table II lists Interface Control Documentation as Type II. ICDs will be Type I in accordance with 5.2.23 of Exhibit A.

Acceptance Review Reports (Item 11) will be Type II in accordance with 5.2.10 of Exhibit A.

5.3 Comments on Exhibit A Appendix I (Quality Program Requirements)

MIT/CSR and the subcontractor will comply with the requirements of Appendix I, paragraphs 1.0, 2.0, 4.0, 5.0, 6.0, and 7.0.

The requirements of Paragraph 3.0 will be met as follows:

In performance of the electronic module assembly work under this contract, the subcontractor shall comply with ND 1002025, "Weld Repair Standard for Resistance Welding of Electronic Circuit Modules and Assemblies" and with ND1002005, "Apollo Requirements for Process Control Fabrication of Resistance Welded Electronic Circuit Modules and Assemblies".

5.4 Comments on Exhibit A, Appendix II (Reliability Program Requirements)

Paragraph 1.0, Line 1: Replace "NPC-250-1" with "NHB 5300.4 (1A)".

5.5 Exhibit A, Appendix III (Configuration Management Requirements)

1.1 Due to the criticality of the delivery schedule, items may be released for manufacture as drawings become available rather than waiting for a complete drawing package suitable for the Critial Design Review. The contractor will provide traceability and configuration control of items fabricated before the Critical Design Review is held.

1.2 No comment.

2.0 No comment.

3.0 No comment.

5.6 Exhibit A, Appendix IV (System Safety Requirements)

MIT/SCR and the subcontractor will implement the requirements of Appendix IV.

5.7 Comments on Exhibit B (Technical Specification).

1.1 No comment.

1.2 No comment.

1.3 No comment.

1.4.1 No comment

1.4.2 No comment.

1.4.3 Insert "Compatibility Unit" in place of "Prototype Hardware."

1.4.4 No comment.

1.4.5 Insert "Interface Mockup" in place of "Mass Mockup Hardware."

1.4.8 No comment.

2.1.3 The GSE specification appears as "MSC-GSE-MEIS-2" and should appear as "MSC-GSE-MEIS-2A."

2.2 No comment.

2.3 No comment.

2.4 No comment.

B

Exhibit B Section 3 (Technical Requirements).

3.1.1.1.1.	First paragraph, third sentence: After " .... and the receiver will be capable of transport on either the MET or LRV" add "with the same interface hardware and orientation."
3.1.1.1.1.	Second paragraph, third sentence: Change to: "All SEP equipment shall be contained in two packages which will interface with Quad III."
3.1.1.1.1.	Second paragraph, twelfth sentence add: "except for the possibility of periodic dusting during traverse."
3.1.1.1.1.	Second paragraph, last sentence; Delete
3.1.1.2	Change "and remaining on the moon in a non-operative status for a period of one week without failure" to "and remaining on the moon in a non-operative status in the equipment bay for a period of 3 days, or on the surface of the moon in a standby status for a period of 3 days without failure." Change "10 continuous hours" to "9 continuous hours."
3.1.1.3	No comment.
3.1.1.4	No comment.
3.1.1.5	First sentence: Replace "one member" with "Members"
3.1.1.5.1	No comment.
3.1.2.1.	The SEP transmitter will conform to the general layout of Figure 3. Details, such as location of handles, may be

4

different than shown.

3.1.2.1.1. Change to: "Size: The transmitter shall not protude beyond a rectangular envelope size of 10" x 10.5" x 11".

3.1.2.1.2. Change to: "Weight - The maximum weight allowed for the transmitter shall be 15 pounds."

3.1.2.1.3. The output power will be sufficient to give the specified range only at the lowest frequency.

3.1.2.1.4. Delete existing wording and replace with: "Transmission Frequency and Timing - The transmitter shall operate at the following six nominal frequencies: 0.5, 1.0, 2.0, 8.0, 16.0 and 32.0 MHz. The transmitter will be stepped through this frequency band once each 3.2 seconds, and 0.4 sec will be allotted for each frequency. During this 0.4 sec transmission interval, transmission will occur first from one linear segment of the antenna for 0.2 sec, then be transferred to the orthogonal linear segment for the remaining 0.2 sec. Additionally, each complete transmission sequence shall include two periods of 0.4 sec each during which the transmitter is turned off; these periods may be used for receiver and background noise calibration measurements.

3.1.2.1.5. No comment.

3.1.2.1.6. The transmitter shall have a power switch for the following operations: (1) off, (2) standby, and (3) on.

3.1.2.1.7. The transmitter shall be capable of continuous operation on the lunar surface during all traverses when the SEP experiment is being conducted.

3.1.2.2. The transmitter antenna shall consist of four multiple-conductor strips which constitute the radiating elements.

3.1.2.3.1. Change to: "Size - The receiver shall not protrude beyond a rectangular envelope of 10 x 13 x 11 inches in the stowed configuration except for the loop antennas which may protrude into the transmitter volume."

3.1.2.3.2. Change to: "Weight - The weight of the receiver including the tape recorder shall not exceed 15.0 pounds."

3.1.2.3.3. Change to: "Sensitivity - The receiver sensitivity shall be such that an input signal of -130 dBm will produce a recorder-output frequency deviation of greater than 1 Hz."

3.1.2.3.4. No comment.

Figure 6. The receiver will conform to the general layout shown in Figure 6. Details such as the shape of the loops and the location of switches may be different. Remove "Transmitter stows here."

3.1.2.3.5. No comment.

3.1.2.3.6. No comment.

3.4.2.3.7. No comment.

3.4.2.3.8. Change "Binary mode switch operation should be employed for the activation of the receiver" to "Receiver activation controls shall be operable by an astromaut on the lunar surface and positive indication of the operating mode shall be given to the astronaut." Change "..on any of the six frequencies" to ..." on one of the six frequencies."

3.1.2.3.9. Once the SEP instrument has been activated no astronaut attention will be required until the end of the traverse unless dust conditions require that the radiator be dusted.

3.1.2.3.10. Remove "and/or replacement".

3.1.2.3.11. The antenna system shall consist of three orthogonal loop antennas as shown in Figure 6a and may have circular rather than rectangular loops.

3.1.2.4.	Add: "An existing tape recorder that will survive the lunar environment may be used without an additional enclosure."
3.1.2.4.1.	No comment.
3.1.2.4.2.	No comment.
3.1.2.4.3.	The recording time will be a minimum of 9 hours after functional test. The operational temperature extremes will be 0°F to 160°F ambient with a heat sink temperature of 35°F to 135°F. The recorder will be flight-qualified and will operate reliably in the lunar environment, but Life and Survival probility are not measurable within the scope of this program and will not be specified.
3.1.2.5.	Delete
3.1.2.5.2	Add: "using estimated values for lunar parameters that affect achievable range."
3.1.3.5.2.	Delete
3.1.2.6.	No comment.
3.1.2.7.1	Item c. Change "separate package and set up transmitter" to "set up transmitter."
3.1.2.7.2.	Delete Item "h".
3.1.2.7.3.	No comment.

3.1.3.1. Item b.6. Facilities for reproducing tapes will be provided by the Tape Processing Equipment (TPE) and the system-test GSE will provide capability for functional test of the tape recorder. Change item b.6 to read: "provide facilities for functional test of the tape recorder."

3.1.3.2. No comment.

3.1.3.3. No comment.

3.1.4.1.1. a. Change to:

The transmitter package dimensions shall be no more than 10 inches by 10.5 inches by 11 inches.

b. Change to:

The receiver package dimensions shall be no more than 10 inches by 12 inches by 11 inches in the stowed configuration except that the loops may protrude into the volume allotted for the transmitter.

c. Change to:

The dimensions of stowed configuration of the complete package shall not exceed 20 inches by 13 inches by 11 inches.

3.1.4.1.2 No comment.

3.1.4.1.3. No comment.

3.1.4.2. No comment.

3.1.4.3. No comment.

3.1.4.4. Add:

Battery packages may be replaced or recharged and tapes and tape recorders may be replaced before launch to satisfy the requirements of this section.

3.1.4.5. No comment.

3.1.4.6. No comment.

3.1.4.7. No comment.

3.1.4.8. No comment.

3.1.4.9. No comment.

3.1.5.1.1. The SEP will be transported to the moon aboard the LM vehicle in Quad III of the descent stage.

3.1.5.2.1. Add:

"with the same interface hardware."

3.2. The SEP flight-hardware-supporting GSE will be designed to MSC-GSE-MEIS-2A, Class II. The Tape Processing Equipment will be designed to MSC-GSE-MEIS-2A Class III.

4.0

Certification test specifications will be prepared in accordance with the requirements of this section and section 5.2.20a of Exhibit A. These documents will be prepared for the deliverable SEP flight instruments and for the SEP GSE.

4.1 No Comment

4.2 No Comment

4.3.1.1.1.g. The Qualification Test procedure requirements will contain recycling and retest requirements in the event of failure during qualification; this will be done to assure minimal delays should a foreseeable failure occur. Should a failure of an unforseen type occur, NASA approval of any new recycling and retest requirements must be available in less than five days to prevent impact on the schedule.

4.3.1.1.1.k. A failure occurring under overstress or off-limit conditions shall not necessarily be construed to be a failure of the qualification test.

4.3.1.1.2.3. The SEP instrument contains significant amounts of insulation and thermal capacity. The temperature of the test article shall be assumed stable when the temperature of the surface of the instrument has stabilized.

4.3.1.1.2.4. See comments on 4.3.1.1.2.3 above.

4.3.1.1.2.5. No comment

4.3.1.1.2.6 No comment

4.3.1.1.2.7. Not applicable

4.3.1.1.2.8. No Comment

4.3.1.1.2.9. No Comment

4.3.1.1.2.10. No Comment

4.3.1.1.2.12. No Comment

4.3.1.1.2.13. The SEP instrument will not be operated in an oxygen environment, so this test is not applicable.

4.3.2.e. The Acceptance Test procedure will contain recycling and retest requirements in the event of failure during acceptance; this will be done to assure minimal delays should a foreseeable failure occur. Should a failure of an unforseen type occur, NASA approval of any new recycling and retest requirements must be available in less than five days to prevent impact on the schedule.

4.3.4. Not Applicable

4.3.5 Not Applicable

SECTION 6

PRINCIPAL INVESTIGATOR TECHNICAL PROPOSAL

SECTION I	ADMINISTRATION/BIOGRAPHICAL
SECTION II	TECHNICAL INFORMATION
SECTION III	SUMMARY OF KEY RESPONSIBILITIES, SUPPORT AREAS AND TASKS
SECTION IV	SURFACE ELECTRICAL PROPERTIES EXPERIMENT STATEMENT OF WORK

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PRINCIPAL INVESTIGATOR PROPOSAL

FOR

MANNED SPACE FLIGHT

SURFACE ELECTRICAL PROPERTIES

S-204
Experiment Number

Principal Investigator ______________ November 10, 1970
Gene Simmons — Date
Earth & Planetary Sciences

Principal Administrator ______________ November 10, 1970
John V. Harrington — Date
Aeronautics & Astronautics
Electrical Engineering

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Center for Space Research

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SECTION I - ADMINISTRATIVE/BIOGRAPHICAL

I-1. APPLICANT INSTITUTION

Massachusetts Institute of Technology 77 Massachusetts Avenue Cambridge, Massachusetts 02139	Telephone: (617) 864-6900

Principal Administrator Responsible for Experiment:

John V. Harrington	Title:	Director, Center for Space Research
Room 37-241, M.I.T.	Telephone:	(617) 864-6900 extension 7501

I-2. PRINCIPAL INVESTIGATOR

Gene Simmons	Title:	Professor of Geophysics
Room 54-314, M.I.T.	Telephone:	(617) 864-6900 extension 6393

Biographical Sketch

The principal investigator has received a B.S. in electrical engineering, an M.S. in geology, and a Ph.D. in geophysics. He is a co-investigator on the Lunar Heat Flow experiment, a part of ALSEP, and has served on various committees for NASA. He has experience in collecting and interpreting geophysical field data as well as laboratory data. Professor Simmons is currently on leave of absence from M.I.T. and is serving as Chief Scientists, NASA Manned Spacecraft Center, Houston.

I-3. Principal Investigator's Role in Relation to This Experiment

This experiment is expected to be truly a team effort. Accordingly, the principal investigator will participate in all of the phases--equipment design and manufacture, preparation of analog models for data reduction, collection of data on the lunar surface, reduction of data, and finally, the interpretation of data. The responsibility of each of the team members who share in this experiment is detailed below in Section I-4. Although the principal investigator is responsible for both the engineering and the scientific aspects of this experiment, most of the actual engineering work done by engineers and/or contractors working for them, will be under the direction of the M.I.T. Center for Space Research. The scientific aspects of the work will be done by the principal investigator and by David Strangway, Anthony England, and their associates.

The principal investigator expects to spend an average of 10 percent of his working time on this experiment in the early phases. During the execution of the experiment on the moon and the early data reduction, full time will be devoted. Finally, in the interpretation phases, about half time will be spent on this experiment. It should be possible to phase the periods of heavy load with those of other work that are currently expected to be in progress during the next few years, namely, the continuation of the lunar samples program and the lunar surface heat flow experiment.

I-4. Responsibilities of Other Key Personnel

Dr. David W. Strangway, a co-investigator, is an associate professor of physics at the University of Toronto currently on leave of absence, and is Chief of the Geophysics Branch of the MSC. In addition to assisting in the general design of the experiment, he is supervising the analog scale-model studies and is assisting in field experiments to test prototype apparatus and the data interpretation thereof. He will devote an average of 20 percent of his time to this project.

Anthony W. England, an astronaut at MSC, also is a co-investigator. He is assisting with the field tests of the engineering models and with the design of the experiment. He will continue to coordinate the interfaces of the experiment with MSC and with the astronaut office. He will participate in the interpretation of the data from the moon. It is expected that he will devote from 5 to 10 percent of his time to this experiment.

Professor John V. Harrington, Director of the Center for Space Research, is responsible for administration of those portions of the program concerned with implementation of this lunar surface experiment, and will devote 10 percent of his time to this project.

Richard H. Baker, Head of the Laboratory for Space Experiments with the Center for Space Research, will spend 75 percent of his time on administrative, coordination and technical considerations involved in the design and fabrication of the lunar surface properties experiment.

I-4. Responsibilities of Other Key Personnel

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Richard H. Baker, Head of the Laboratory for Space Experiments with the Center for Space Research, will spend 75 percent of his time on administrative, coordination and technical considerations involved in the design and fabrication of the lunar surface properties experiment.

Lawrence H. Bannister, Staff Member, Center for Space Research, will be Project Leader for the Experiment Design, and will devote 100 percent of his time to this project. He and Mr. Baker will lead the engineering group that controls the configuration, and monitor the various design tests on models through the engineering hardware stage. Additionally, Mr. Baker and Mr. Bannister will be responsible for and participate in ensuring R&D tests and data interpretation under the control of the PI.

Raymond D. Watts is completing his Ph.D. requirements at the University of Toronto and will be a research associate at the Lunar Science Institute in the fall of 1970. He will develop computerized techniques to interpret the data returned from the moon. He will devote 50 percent of his time to this project.

Gerald A. LaTorraca is a graduate student at M.I.T. He will work closely with the CSR in all phases of this program and will assist in testing these models in the field. He will devote 100 percent of his time to the project.

James R. Rossiter is a graduate student at the University of Toronto and will be a graduate fellow of the Lunar Science Institute in late 1970. He is conducting analog scale-model studies and will assist in field tests of apparatus and in data interpretation. He will devote 100 percent of his time to this project.

SECTION II - TECHNICAL INFORMATION

II-1. OBJECTIVES

The chief objectives of this experiment are to determine layering in the lunar subsurface, and to search for the presence of water at depth. In addition, the electrical properties of the lunar material will be measured in situ. Under favorable conditions, it may be possible to obtain an independent estimate of the lunar thermal flux and an indication of the number and size of subsurface scattering bodies.

II-2. SIGNIFICANCE

It is difficult to overstate the significance of a clear demonstration of the presence or absence of water in the lunar interior. Many of the surface features have been attributed to past erosion by water or ice. Igneous processes, as we know them on earth, depend on the presence of water to reduce the melting points of silicates. But the absence of water in the moon would demonstrate that igneous processes do not operate on the moon in an analogous fashion to those on the earth. This would imply greatly different thermal models for the two bodies. Thus the search for water in the lunar interior is scientifically very important.

Examination of the samples returned on Apollo 11 and Apollo 12 indicated an unusual absence of water. Few hydrous minerals were found. The assemblage of iron-troilite-ilmenite suggests a very low partial pressure of H_2O during formation of the rocks which are now residing on the surface. This finding is in agreement with radar measurements made from Earth and from Lunar Orbiters, which indicate a very low electrical conductivity of the material at the surface of the moon. Therefore, the amount of water, either free or bound in crystal lattices, at the surface of the moon is known to be extremely low. However, the available data leave completely unanswered the critical question of whether or not water exists at depth in the moon.

It is the purpose of this experiment to measure the electrical properties of the lunar subsurface as a function of depth. Since the presence of even minute amounts of water in rocks changes the electrical conductivity by several orders of magnitude, any moisture present would be easily detected by this experiment. Thus upper bounds can be set on the amount of water in the lunar subsurface to depths of a few Kilometers.

The frequency range of the experiment has been selected to allow determination of layering over a range of depths from a few meters to a few Kilometers. Accordingly it may be possible to determine the thickness of the outer layer, commonly referred to as the regolith or the 'gardened layer', in the vicinity of the landing site. Such layering could be detected by the expected change in dielectric properties and conductivity. This subsurface topographic information holds considerable implications for the history of the outer few Kilometers of the moon.

Moreover, the presence of water in the moon would allow a determination of the amount of heat flowing from the interior of the moon to the surface. The electrical properties experiment, under favorable conditions, could provide a determination of the depth at which any moisture present changed from the solid to liquid form. Thus the approximate depth to the zero-degree isotherm could be found. This depth, together with the knowledge of thermal conductivity estimated from lunar samples, could give an estimate of the lunar thermal flux. This, in turn, would provide important clues to the nature of the moon's core.

Recent seismic experiments have indicated that a large amount of scattering material may be present in the lunar subsurface. Since electromagnetic propagation in this experiment will be sensitive to these scattering bodies, and since a number of different wavelengths are being used, a measure of the size and number of scattering bodies also might be possible. This would give additional valuable information on the nature of the outer few Kilometers of the moon.

Therefore, the experiment will provide a wealth of information on the properties of the lunar subsurface. It is a valuable experiment which will help to determine the lunar history better than previously possible, and which relates to, and complements, other scientific studies of the moon already in progress.

II-3. DISCIPLINARY RELATIONSHIP

A. Brief history of related work.

Most geological environments on earth are too conductive due to the presence of moisture, to allow penetration of high frequency electromagnetic radiation. Therefore, radio frequency interferometry has had little development as a geophysical tool. However, the idea is not new. It was suggested by Stern (reported by Evans, 1963) as early as 1927, but was not developed as a field technique. Although the interpretation of his field results is open to some question, El-Said (1956) attempted to use the method to determine the depth to the water table in the Sahara Desert.

For this technique of sounding to be effective, the medium being probed must have low electromagnetic losses. Ice provides one of the few earth environments which meets this condition. It is highly resistive (Evans, 1965) and the bottom offers a good contrast. For this reason, radar pulses have recently been used to sound large ice sheets and glaciers (Evans, 1963; Rinker et al, 1964; Bailey et al, 1964; Walford, 1964; Jiracek, 1967), and glaciers have provided suitable sites to test the interferometry technique. (Annan, 1970).

There are many indications that the lunar surface is also very resistive. Radar measurements have indicated that lunar surface material has electrical properties similar to those of dry, powdered, terrestrial rocks and is, therefore, transparent to radio waves (England et al, 1968; Campbell and Ulrichs, 1969; Strangway, 1969; St. Amant and Strangway, 1970). Initial experiments on lunar samples indicate that the dielectric constant and loss tangent of lunar rocks are, in fact, similar to those of dried terrestrial rocks (Chung et al, 1970; Gold et al, 1970).

B. State of present development in the field.

The present state of development of the experiment is based largely on the research conducted by the group of investigators who are submitting the proposal, and their co-workers. This research falls into four main areas:

(i) electrical properties of both terrestrial and lunar rocks;

(ii) theoretical solutions of the various field components associated with magnetic and electric dipoles above a dielectric layer, including computed results;

(iii) scale model studies of a dipole over a dielectric layer; and

(iv) field results using prototype apparatus on glaciers.

The state of development of each of these areas will be summarized here.

(i) Electrical properties of rocks

Several workers have now completed initial studies of the electrical properties of the returned lunar samples.

The results of these studies, summarized in Table II-1, indicate that the electric properties of lunar rocks are not much different from those of dried terrestrial rocks. The losses for a variety of dried terrestrial rocks in a vacuum are very low; the loss tangent, tan δ, typically is less than 0.01 at 1 Megahertz. The dielectric constant K, depends largely on the density and ranges from about 3 for the powders, up to about 10 for the solid rocks.

Gold et al (1970) measured the attenuation distance of some Apollo 11 fines to be about 10 wavelengths at 450 MHz., which is in agreement with many previous radar studies. This gives a loss tangent of about 0.02; the dielectric constant of these fines was about 2.4. Work on various solid samples from Apollo 11 has been completed by Chung et al (1970). Their lunar breccia has a dielectric constant between 15 and 20 for the frequency range around 1 MHz., and the igneous sample has a K between 11 and 14. At 25°C. these samples show a loss tangent of about 0.05 and 0.16 respectively. These losses are somewhat higher than those of the terrestrial rocks, possibly due to residual moisture in the sample. This is partly confirmed by work done on Apollo 12 sample 12002 (Chung, 1970) under very dry conditions, for which $k = 10$, and $\tan \delta = 0.055$, at 1 MHz. at 25°C.

Table II - 1 Summary of Dielectric Properties of Terrestrial and Lunar Rocks

Material	Bulk Density (gm/cc)	High Frequency Dielectric Constant K_∞	Loss Tangent $\tan\delta$	D.C. Conductivity (mhos/m.)
Powders (St. Amant and Strangway, 1970)			at 1 MHz., 27°C	27°C
Plagioclase	1.54	3.3	0.003	1×10^{-15}
Augite	1.66	4.4	0.03	-
Hypersthene	1.67	3.1	0.001	-
Basalt (1)	1.46	3.1	0.01	1×10^{-13}-6×10^{-12}
Basalt (2)	1.42	3.2	0.01	6×10^{-15}-7×10^{-17}
Granite	1.44	2.9	0.003	5×10^{-16}
Dunite	1.83	3.4	0.003	1×10^{-16}
Solids				
Basalt (2)	2.95	10.1	0.03	3×10^{-10}
Granite	2.71	6.4	0.01	6×10^{-13}
Dunite	3.32	8.2	0.003	1×10^{-15}
Lunar Powder (Gold et al, 1970)				
Apollo 11 fines	1.57	2.4 at 450 MHz.	0.02 at 450 MHz.	-
Lunar Samples (Chung et al, 1970)				
10020 (igneous)	3.18	10 - 15	0.09 - 0.2	10^{-7} - 10^{-9}
10057 (igneous)	2.88	9 - 13	0.09 - 0.2	10^{-7} - 10^{-9}
10046 (breccia)	2.21	6 - 9	0.05 - 0.09	10^{-8} - 10^{-9}
12002 Unpublished data		10	0.055	

The lunar samples of Chung et al have losses which show a fairly strong increase with temperature. This effect also is seen at lower frequencies in terrestrial rocks.

Some work has been done on the magnetic losses of the lunar samples using pulses (Olhoeft and Strangway, 1970). There appears to be some magnetic induction effects, but these are not likely to be pronounced at frequencies around 1 MHz.

A summary of the attenuation distance of electromagnetic waves, estimated from various lunar measurements, is shown in Figure II-1.

It is concluded from these studies that the electromagnetic losses to be expected on the moon may be greater than those for very dry terrestrial rocks, but are still very low. Typical penetration depths are in the range of Kilometers for frequencies around 1 MHz.

(ii) Theoretical solutions

Several theoretical results of interest have been derived by the group of investigators and their co-workers. The easiest solutions are for the configuration of a vertical magnetic dipole, over a dielectric layer, over a horizontal reflector, as shown in Figure II-2. The field component of interest is E_ϕ, the electric field measured tangential to an imaginary cylinder which encloses the dipole and has the same axis. These results are covered by Annan (1970). Suites

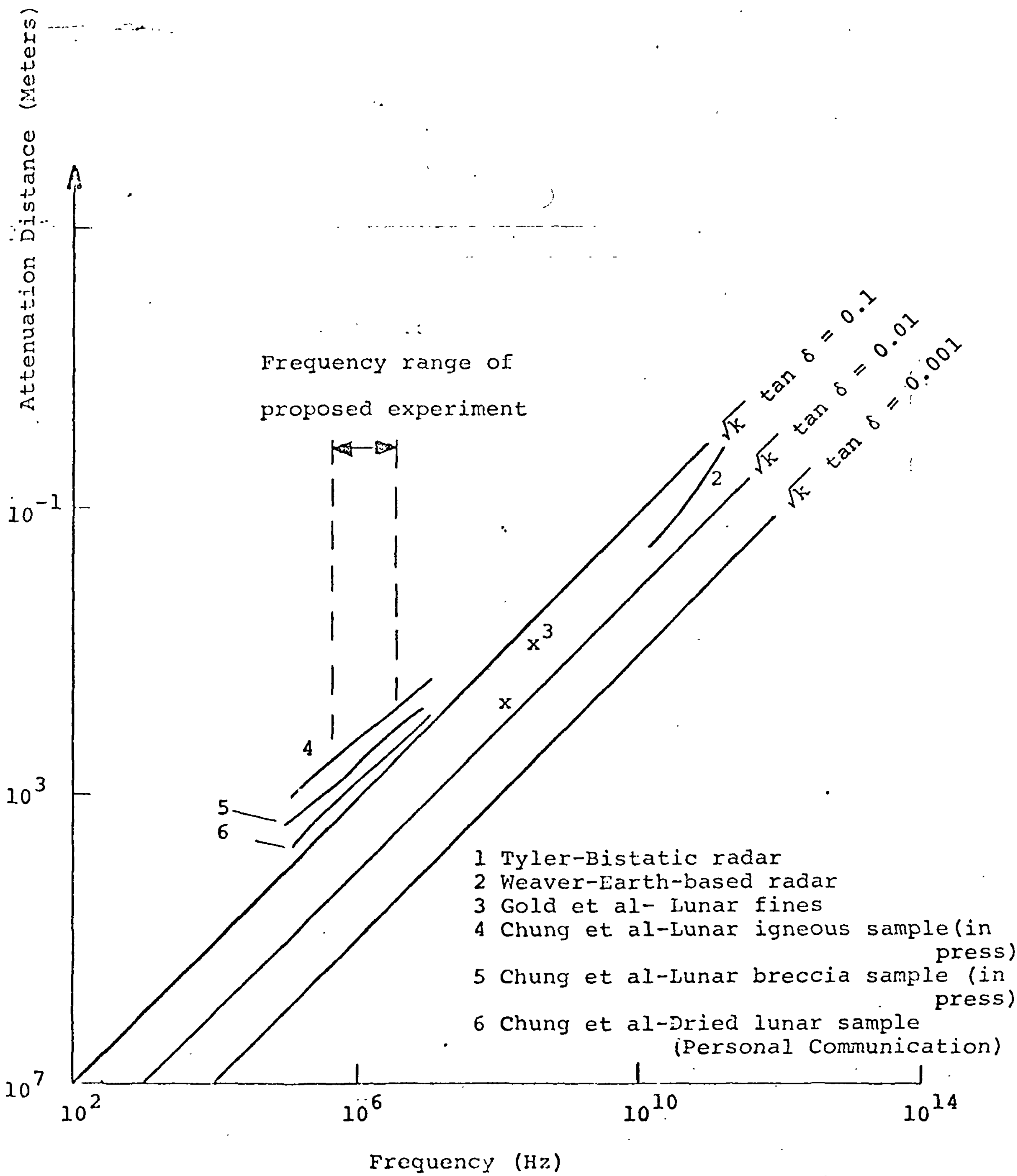


Figure II-1: ATTENUATION DISTANCE DEDUCED FROM VARIOUS LUNAR MEASUREMENTS.

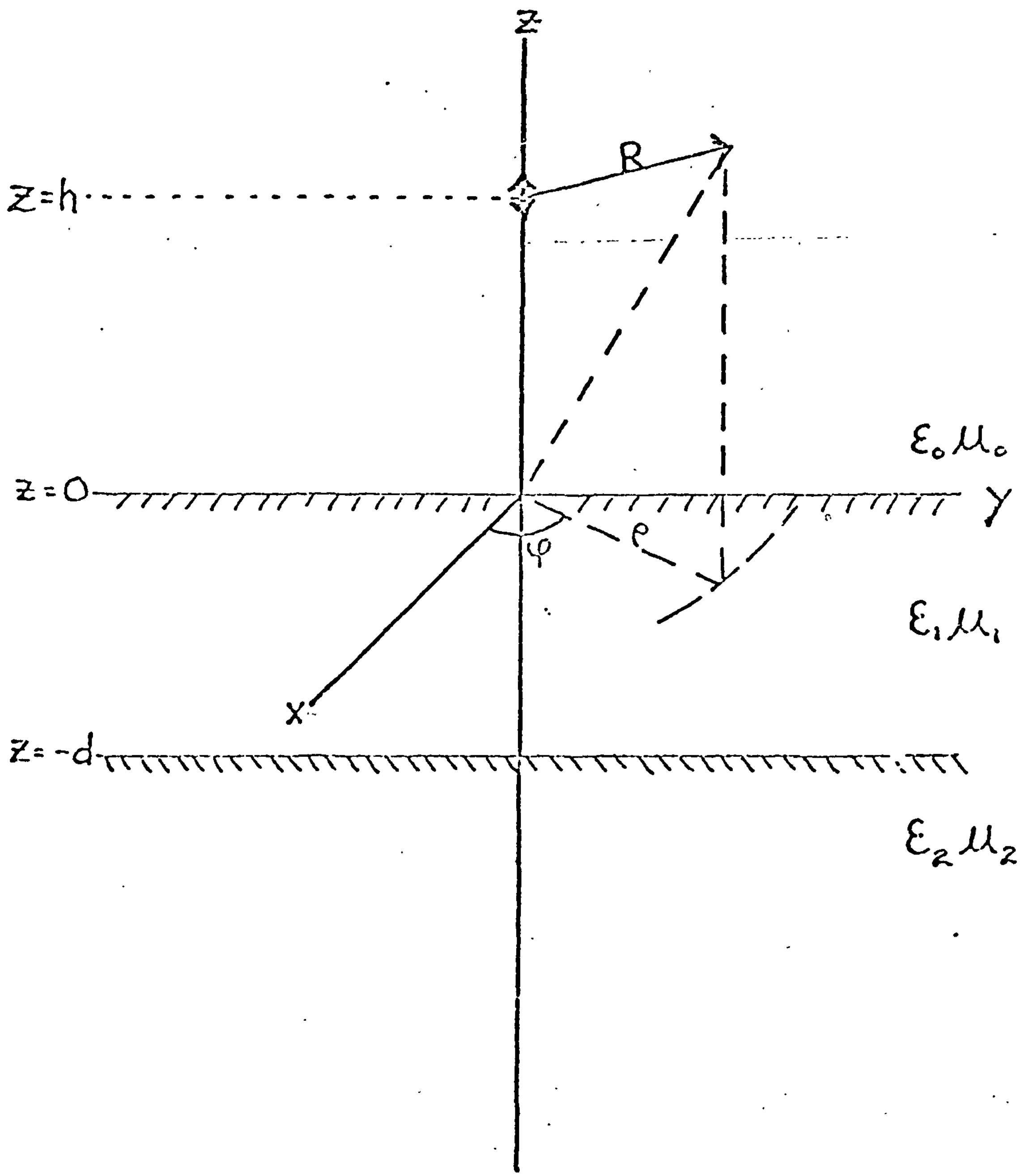
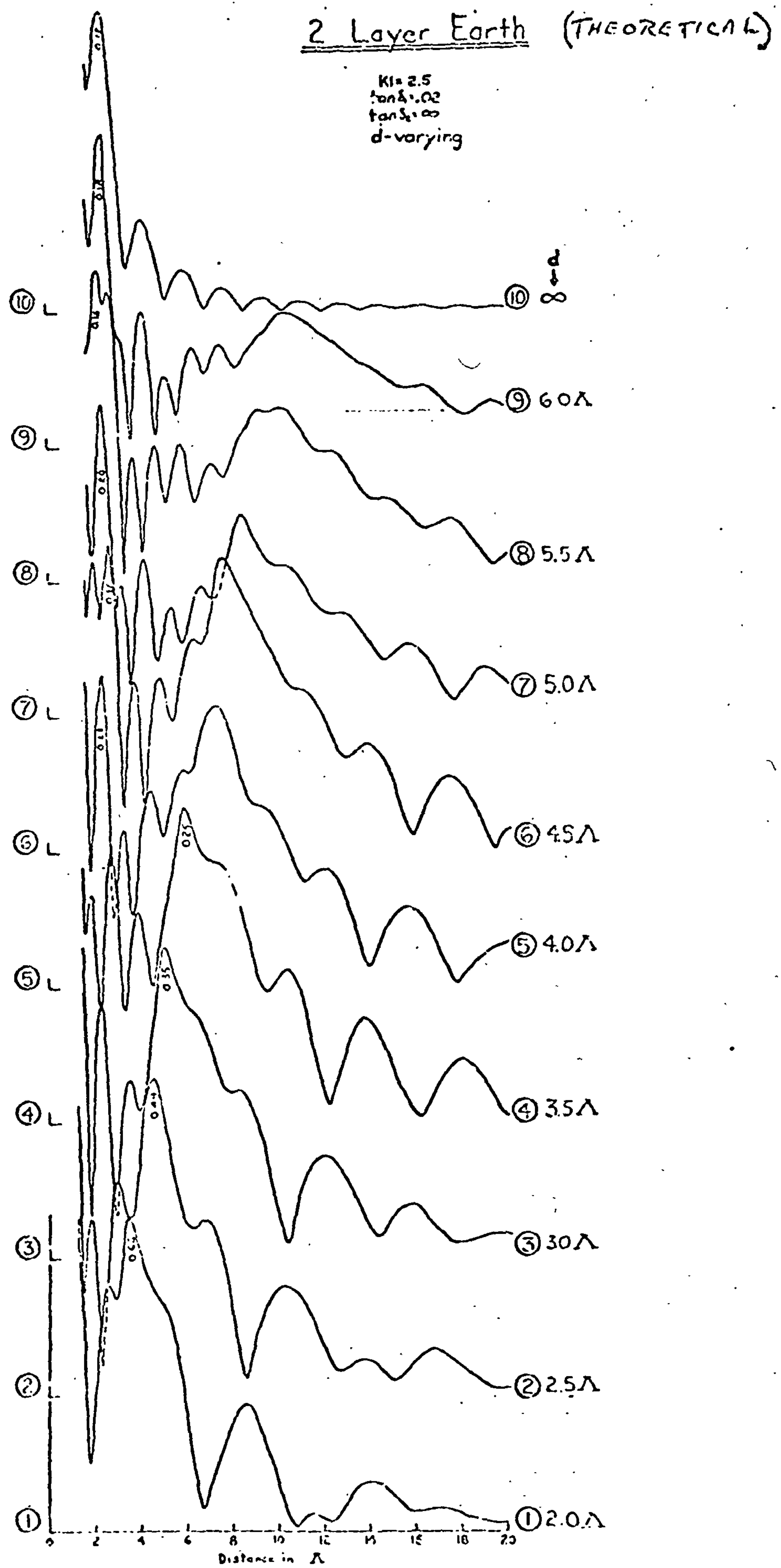


Figure II-2 VERTICAL MAGNETIC DIPOLE OVER A TWO LAYER EARTH of curves have been computed, and samples of these are shown in Figures II-3 to II-5. These curves show how sensitive the technique is to the depth of the reflector, d, the dielectric constant, K, and the loss tangent, tan δ.

Solutions for a horizontal electric dipole over a dielectric layer, which is the system we propose to use, are more complex. To illustrate the components of interest, Figure II-6 shows the orientation. Results have been computed for the vertical magnetic field, Hz, and the radial magnetic component, $H\rho$. The Hz component should be simply related to the tangential electric field of the vertical magnetic dipole, $E\phi$, and this has been verified in the field. $H\phi$, the tangential magnetic field, theoretically should equal zero for a homogeneous layer over a horizontal reflector. Since in the field it has been found that this component does not always vanish, it can be used as a measure of inhomogeneity and scattering. A typical suite of curves for $H\rho$ is shown in Figure II-7.

(iii) Scale-model experiment

The theoretical results have been backed up by scale-model studies. Using a vertical magnetic dipole over a layer of sand covering an aluminum reflecting sheet, Annan got good agreement with the theory. Typical model results are shown in Figure II-8 along with their theoretical counterparts in Figure II-9. Although the agreement is not perfect, most of



2 Layer Earth (THEORETICAL)
K1=2.5
tanδ1=.02
tanδ2=∞
d-varying
d
⑩ L
⑩ ∞
⑨ L
⑨ 6.0Λ
⑧ L
⑧ 5.5Λ
⑦ L
⑦ 5.0Λ
⑥ L
⑥ 4.5Λ
⑤ L
⑤ 4.0Λ
④ L
④ 3.5Λ
③ L
③ 3.0Λ
② L
② 2.5Λ
①
① 2.0Λ
Distance in Λ

Figure II-3

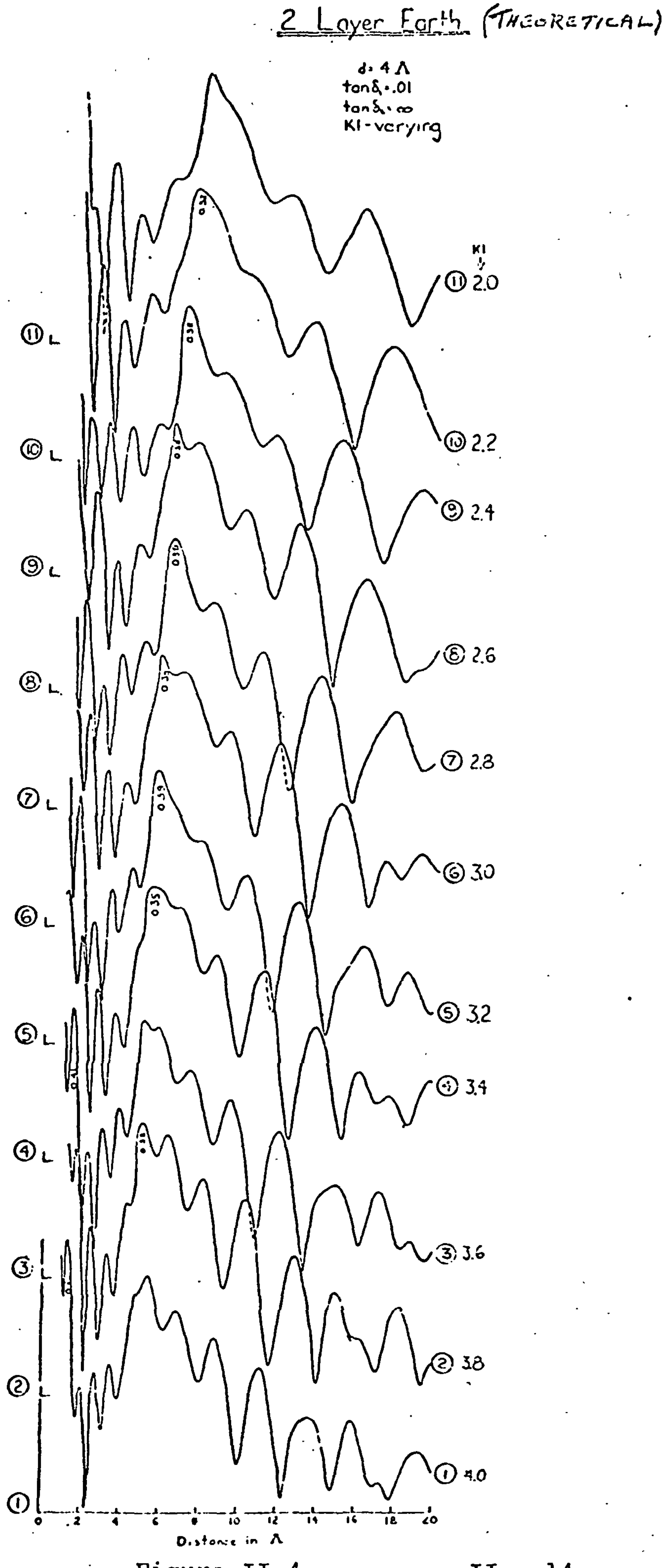

2 Layer Earth (THEORETICAL)
d = 4 λ
tan δ = .01
tan δ = ∞
K1 - varying
K1
① 2.0
⑩ 2.2
⑨ 2.4
⑧ 2.6
⑦ 2.8
⑥ 3.0
⑤ 3.2
④ 3.4
③ 3.6
② 3.8
① 4.0
Distance in λ

Figure II-4

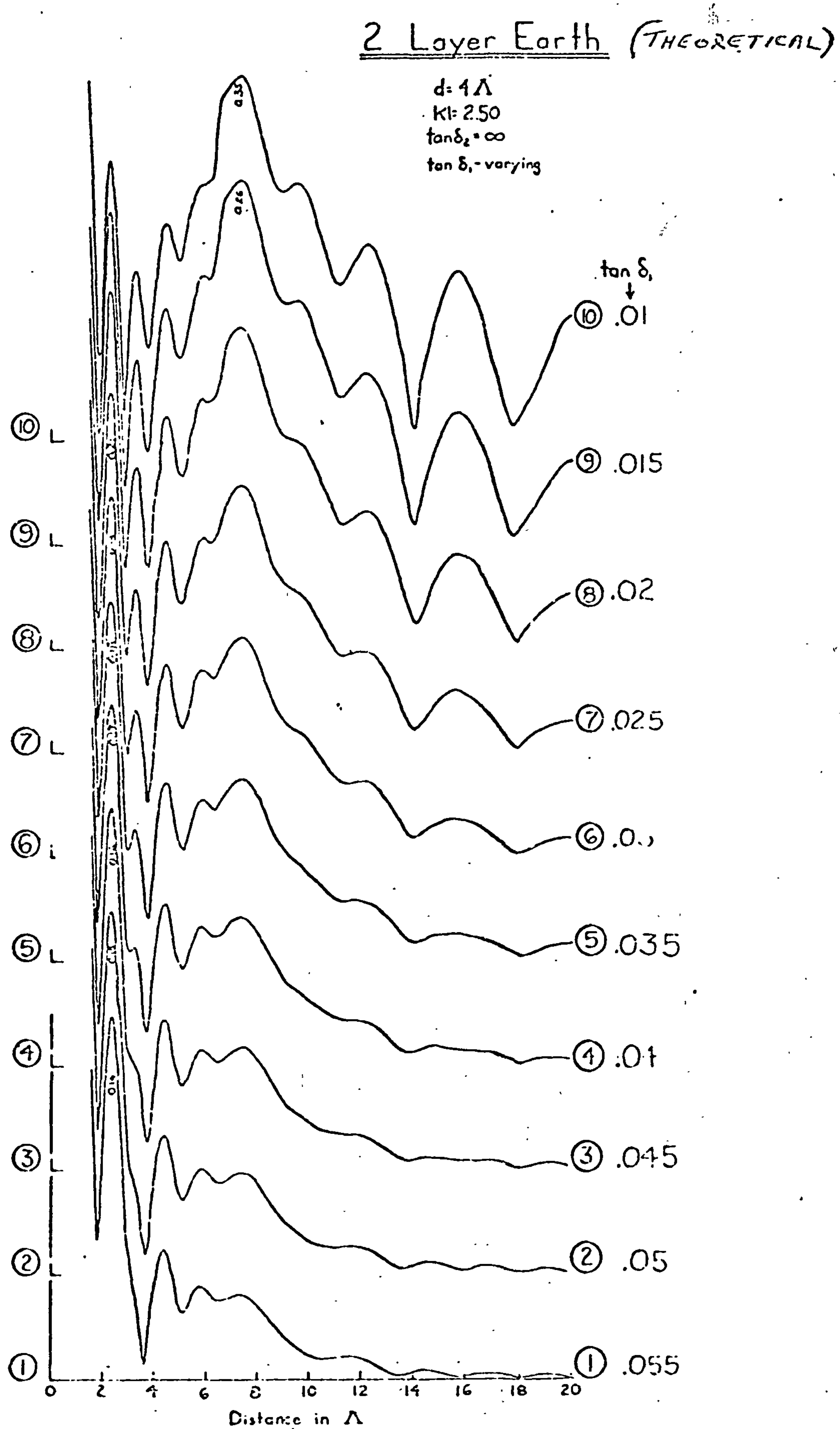

2 Layer Earth (THEORETICAL)
d: 4Λ
Kl: 2.50
tanδ₂ = ∞
tan δ₁ - varying
tan δ₁
10 .01
9 .015
8 .02
7 .025
5 .035
3 .045
2 .05
1 .055
0 2 4 6 8 10 12 14 16 18 20
Distance in Λ

Figure II-5

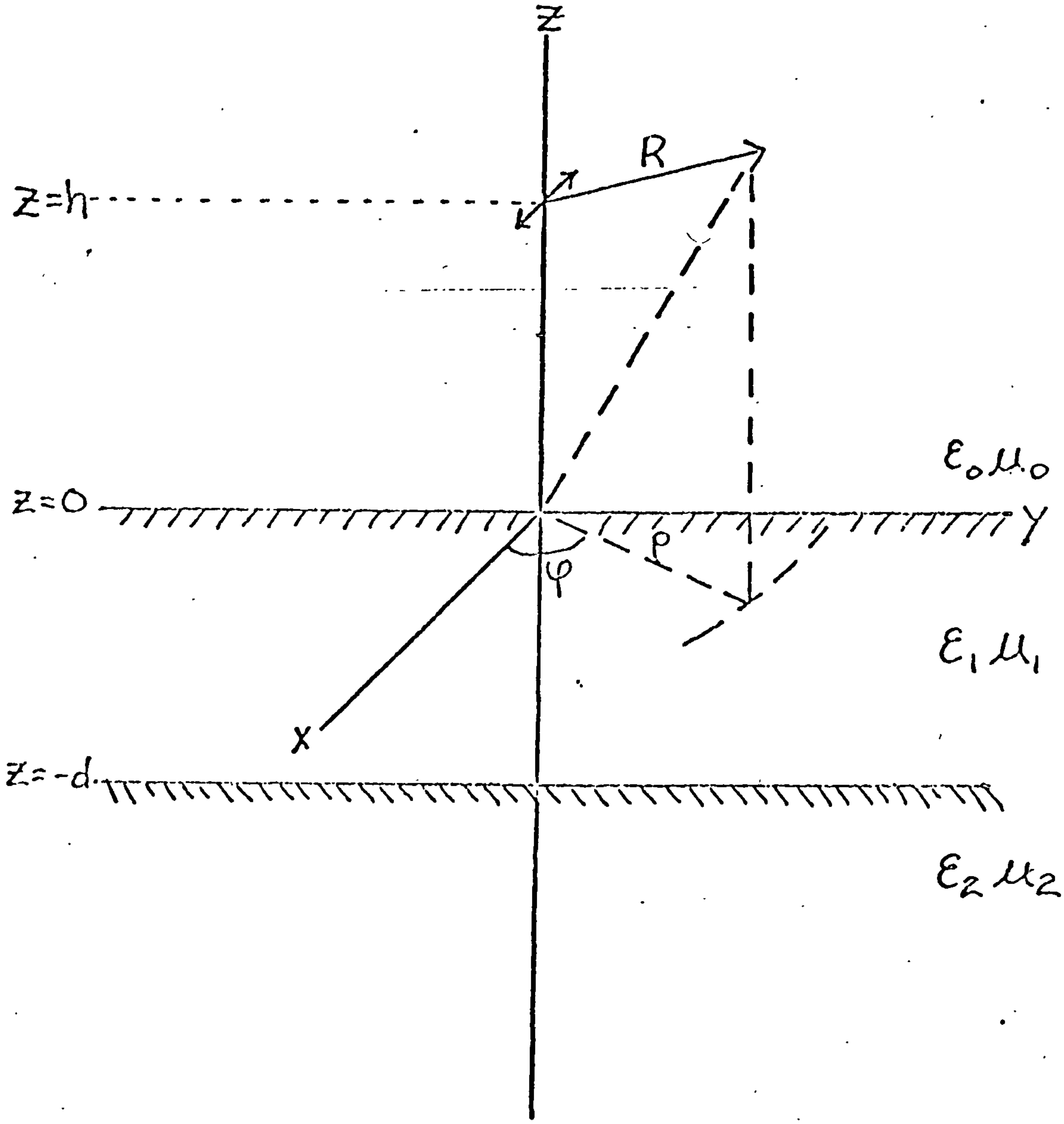


Figure II-6 HORIZONTAL ELECTRIC DIPOLE OVER A TWO LAYER EARTH

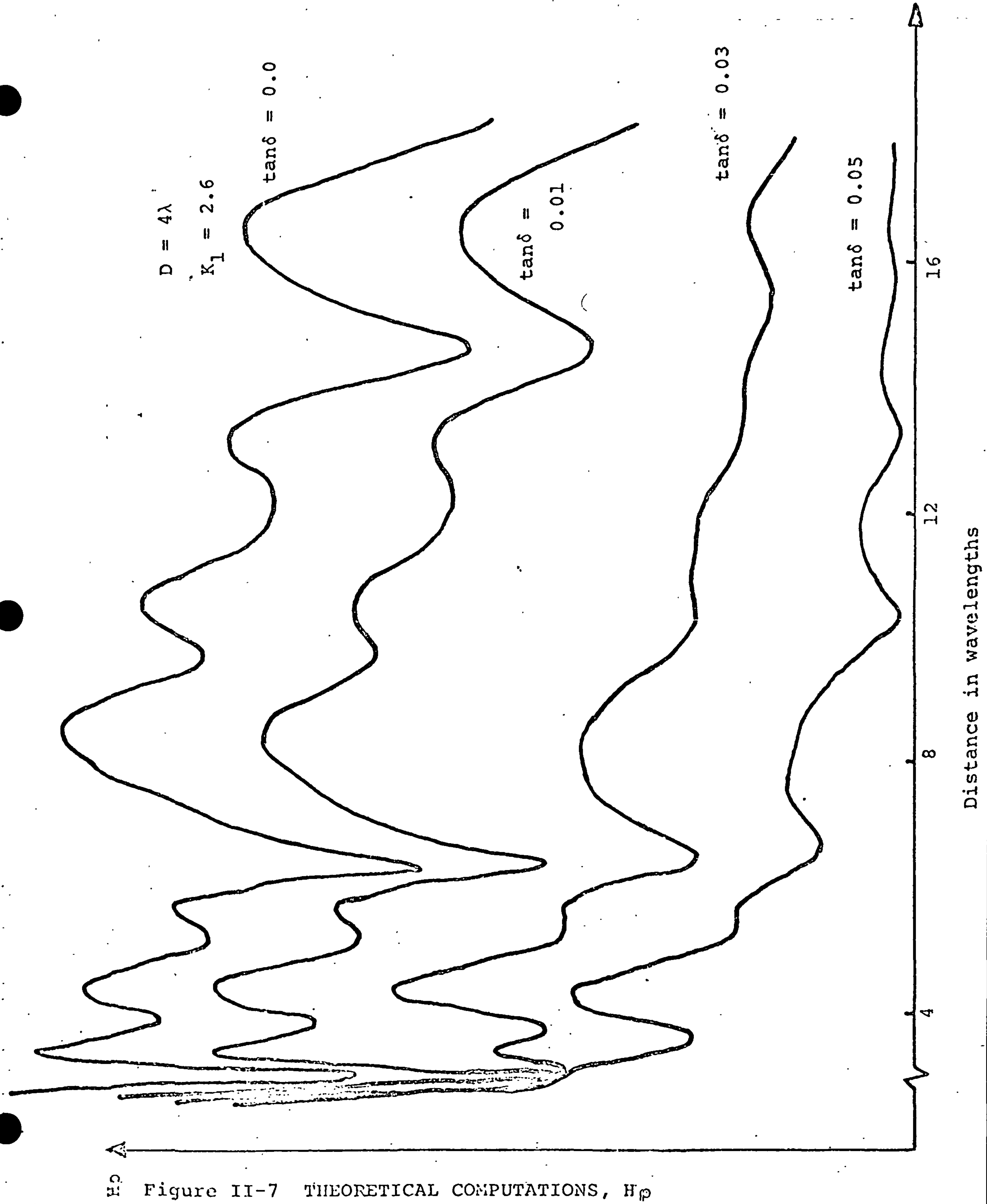


Figure II-7 THEORETICAL COMPUTATIONS, Hρ

Model 2 Layer Earth

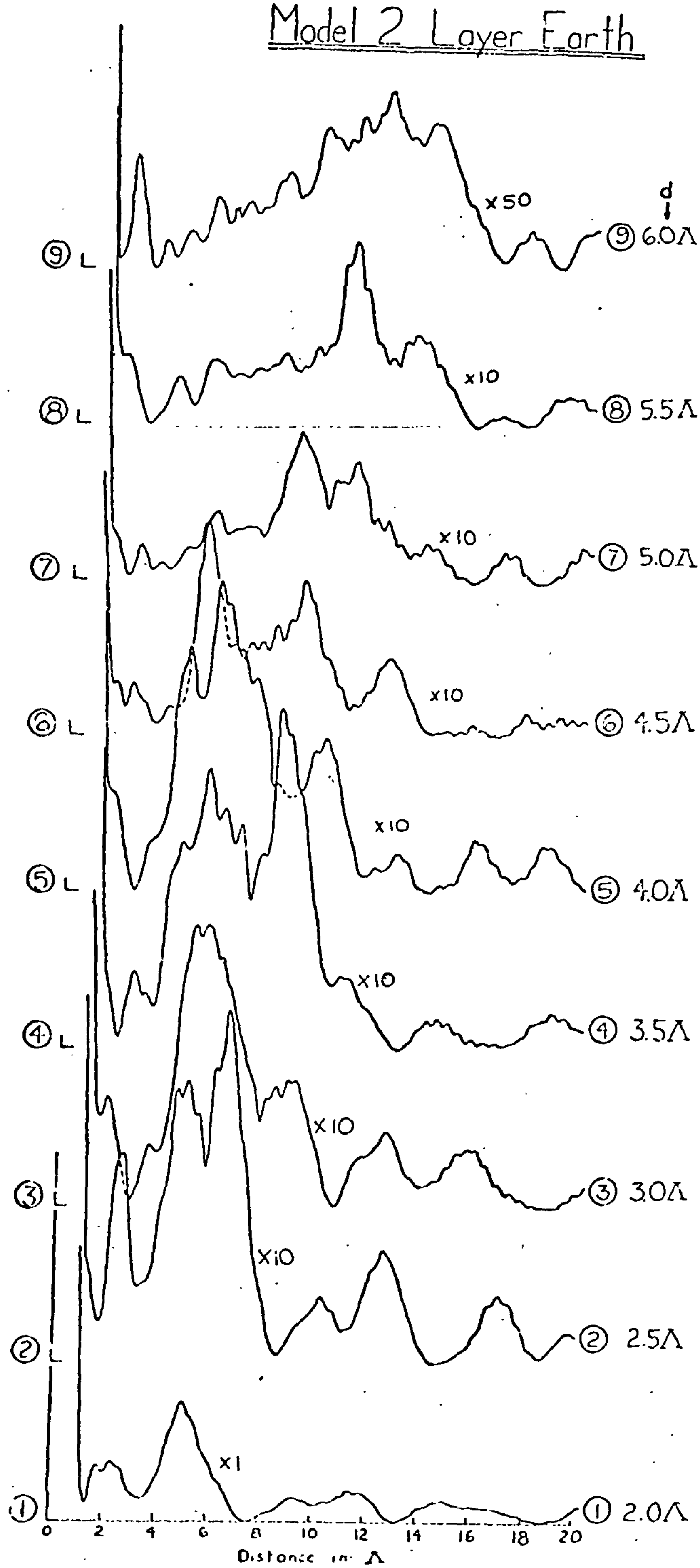


Figure II-8

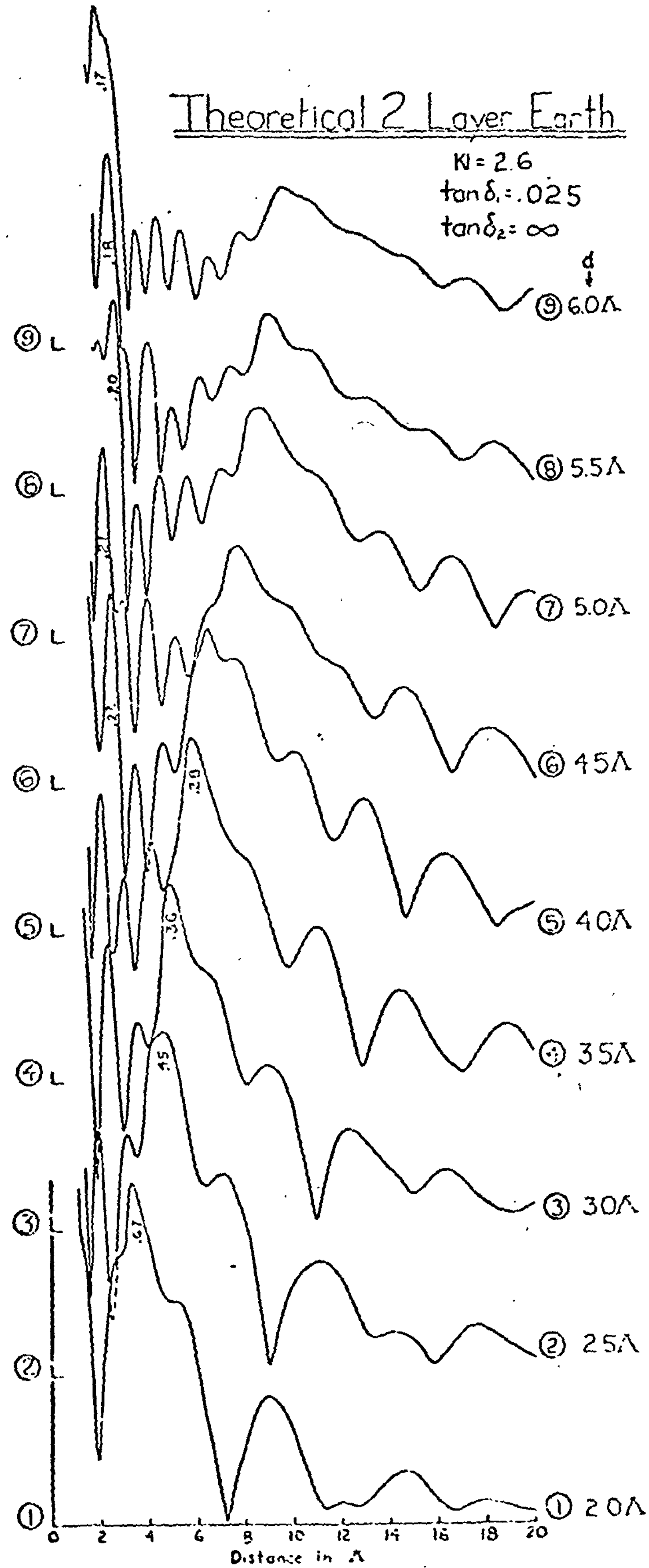

Theoretical 2 Layer Earth
N = 2.6
tan δ₁ = .025
tan δ₂ = ∞
d
⑨ 6.0Λ
⑧ 5.5Λ
⑦ 5.0Λ
⑥ 4.5Λ
⑤ 4.0Λ
④ 3.5Λ
③ 3.0Λ
② 2.5Λ
① 2.0Λ
⑨ L
⑧ L
⑦ L
⑥ L
⑤ L
④ L
③ L
② L
①
0 2 4 6 8 10 12 14 16 18 20
Distance in Λ

Figure II-9

the discrepancies can be explained by the limitations of the experimental model. Work is now in progress to construct a more sophisticated model, which will hopefully overcome most of the observed difficulties and will have the capability of modeling a larger variety of cases.

(iv) Glacier tests

The ultimate test of a new method is in the field. In order to evaluate the interferometry technique, three major field tests have been conducted. The first, over the 450 meter deep Gorner Glacier, gave conclusive proof that the method is able to determine the electrical properties of a dielectric medium in situ. This is shown by Figure II-10, where it can be seen that the dielectric constant of ice is about 3.2 as expected.

Using an engineering breadboard of the transmitter, a series of field trials were made on the shallower, 150 meter deep, Athabasca Glacier. Although a complete interpretation of the results is not yet available, the experiment indicated that the technique will give the depth to a reflector in a geological environment which has low electromagnetic losses. Preliminary results show that the field data give reasonable agreement with the theoretical results produced so far, in spite of the inherent limitations of the present experimental unit. (It is very tedious and time consuming to hand record and reduce the data.) A few typical comparisons are shown in Figures II-11 to II-14.

Comparison of Theoretical and Experimental Profiles

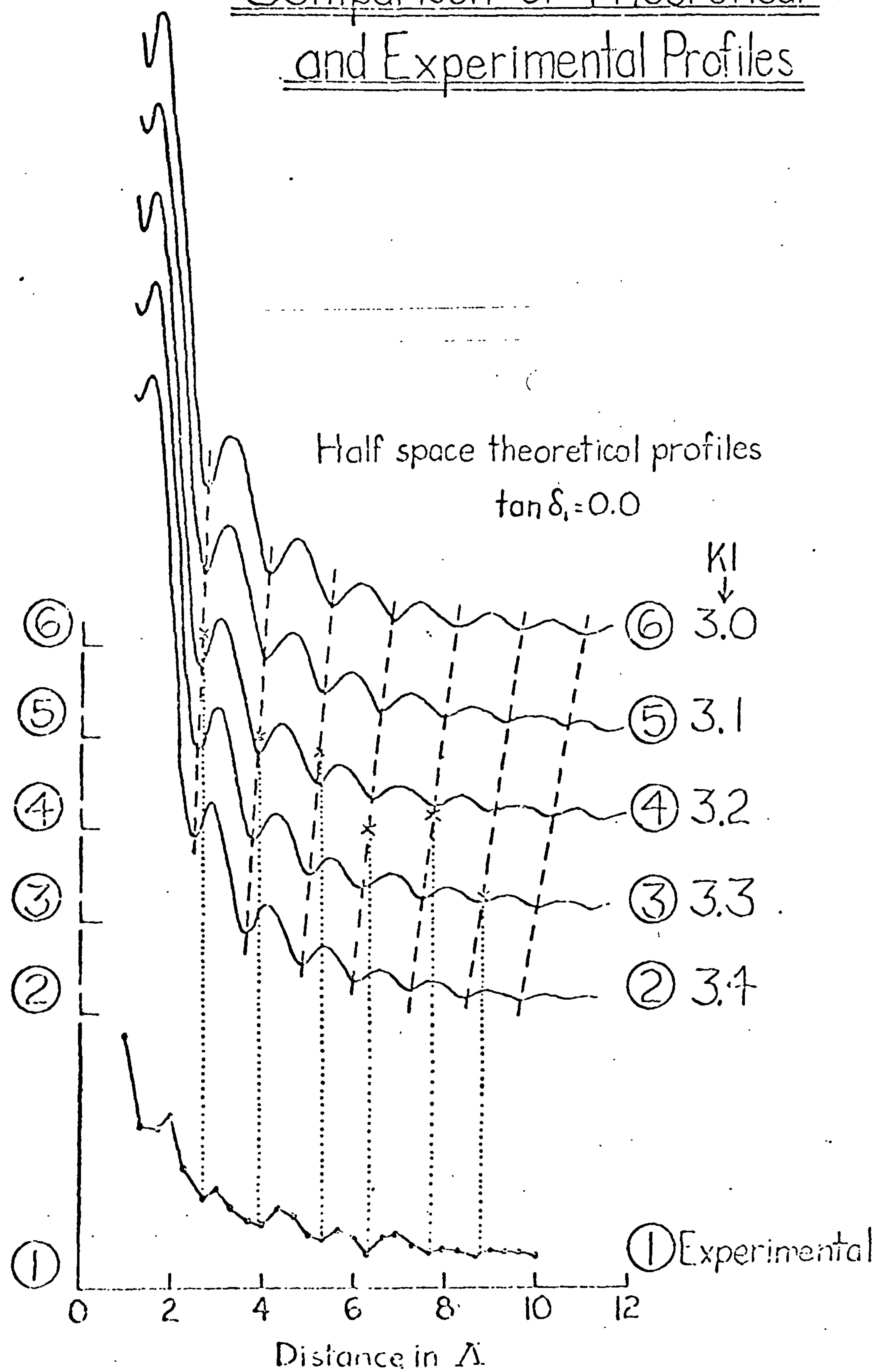


Figure II-10

(v) Summary of present developments

Studies of the electrical properties of lunar material indicate that the electromagnetic losses are adequately small in the chosen frequency range. The interferometry technique has been studied theoretically with scale models and in the field. Although work is continuing, the present results agree sufficiently well to show that the technique will give in situ electric properties and the depth to a subsurface reflector.

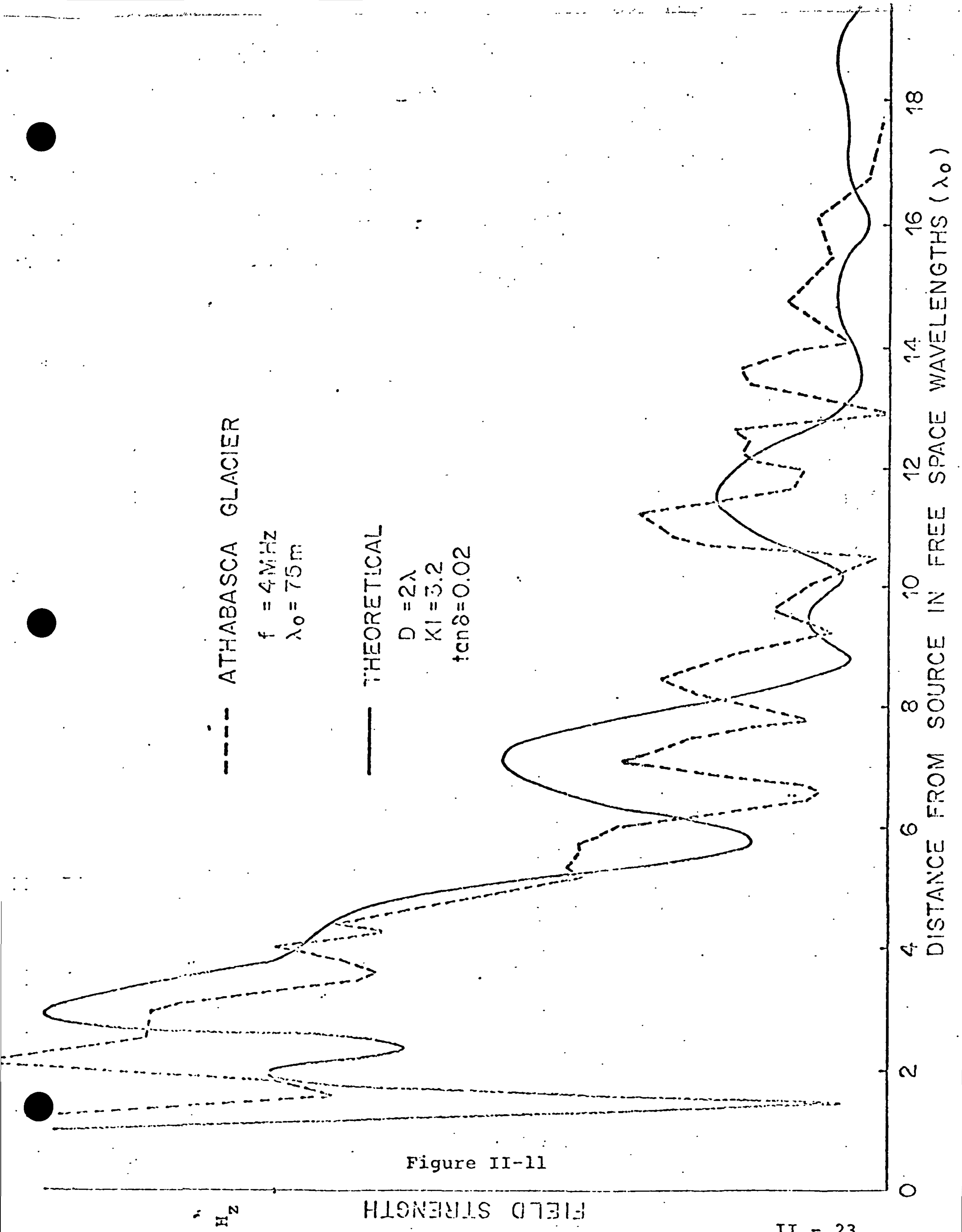
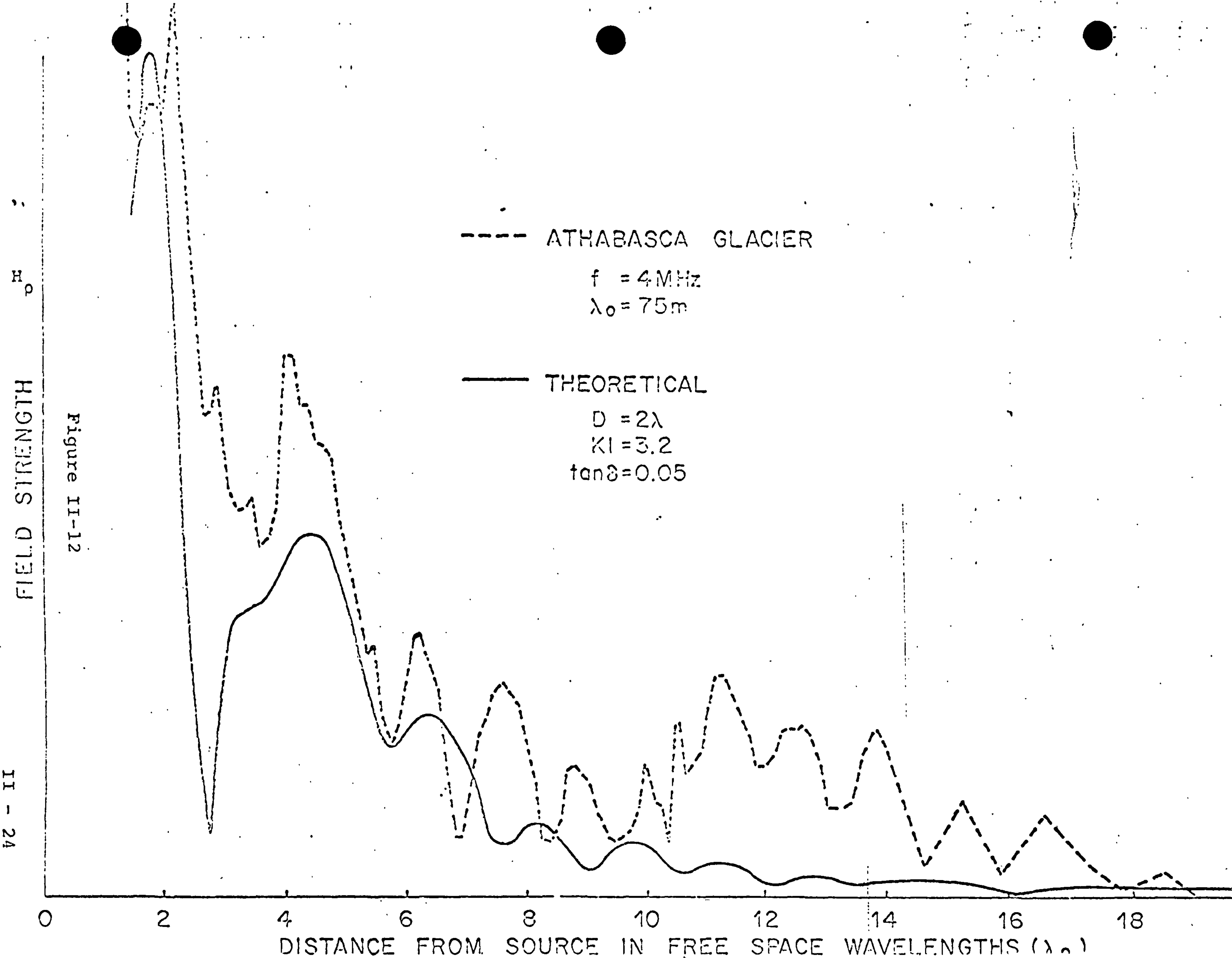
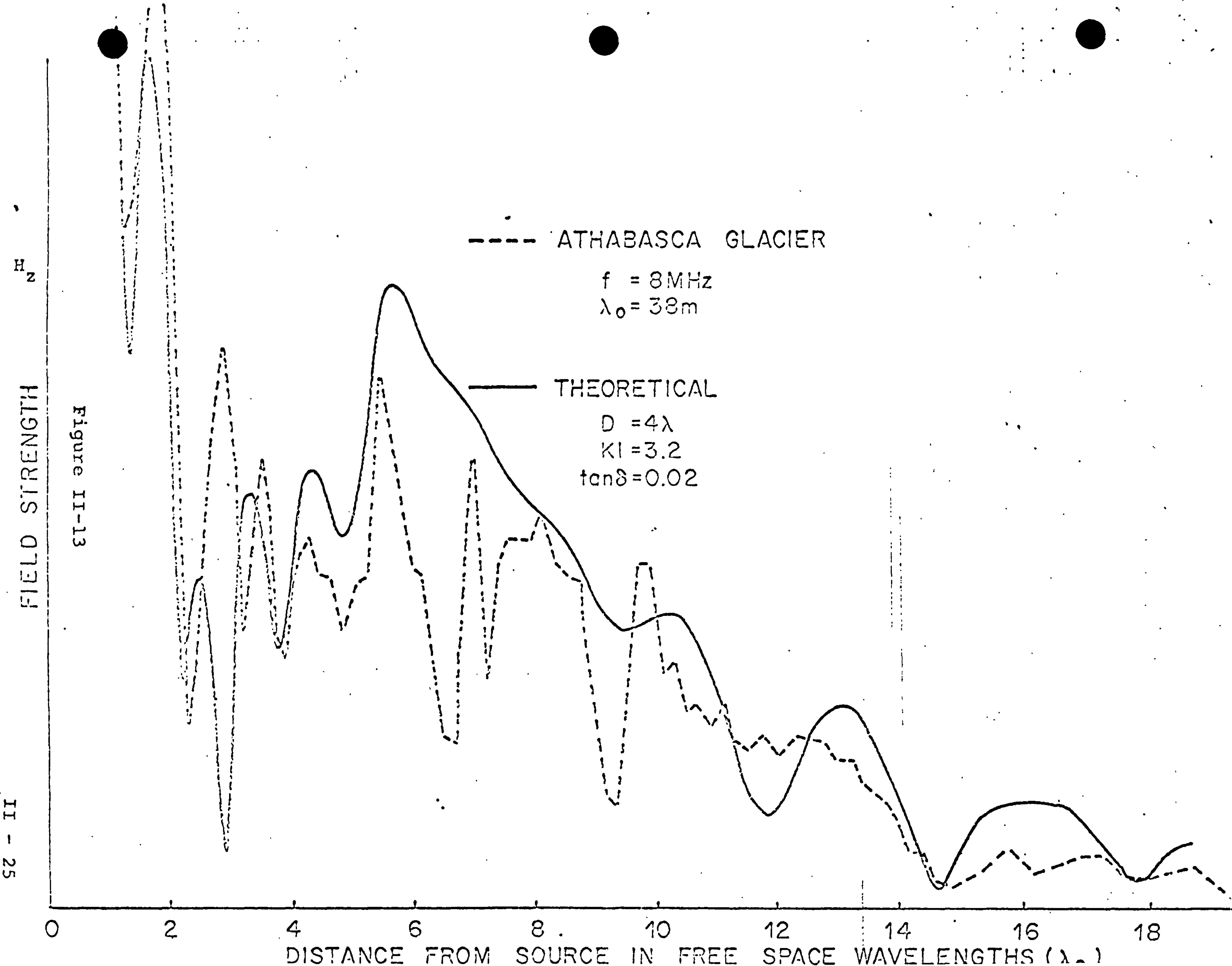

ATHABASCA GLACIER
f = 4MHz
λo = 75m
THEORETICAL
D = 2λ
Kl = 3.2
tanδ=0.02
DISTANCE FROM SOURCE IN FREE SPACE WAVELENGTHS (λo)
0
2
4
6
8
10
12
14
16
18
FIELD STRENGTH
Hz

Figure II-11



---- ATHABASCA GLACIER
f = 4MHz
λo = 75m
—— THEORETICAL
D = 2λ
KI = 3.2
tanδ=0.05
FIELD STRENGTH
Hρ
0
2
4
6
8
10
12
14
16
18
DISTANCE FROM SOURCE IN FREE SPACE WAVELENGTHS (λo)

Figure II-12



ATHABASCA GLACIER
f = 8MHz
λ_o = 38m
THEORETICAL
D = 4λ
KI = 3.2
tanδ = 0.02
FIELD STRENGTH
H_z
0
2
4
6
8
10
12
14
16
18
DISTANCE FROM SOURCE IN FREE SPACE WAVELENGTHS (λ_o)

Figure II-13

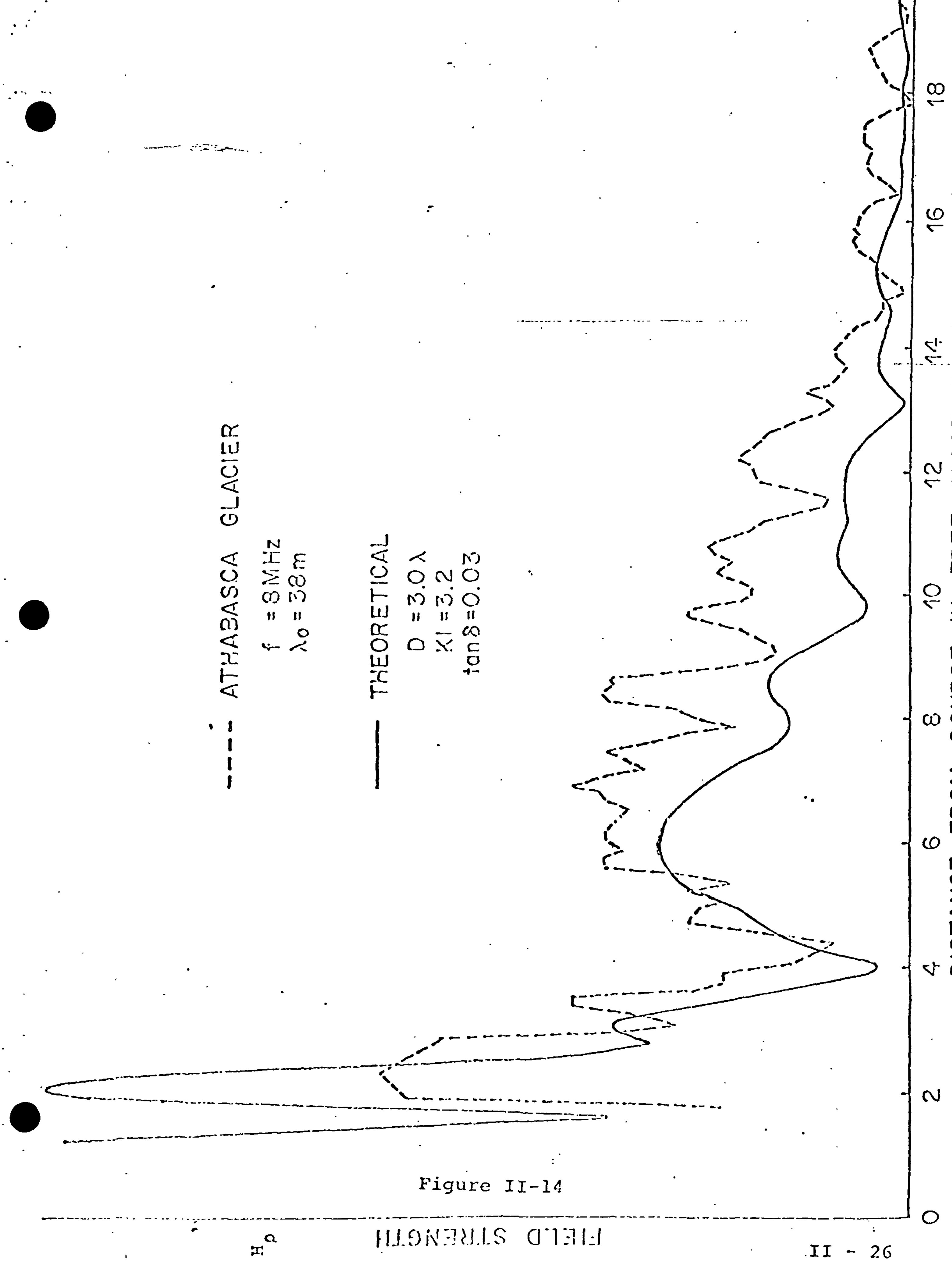

ATHABASCA GLACIER
f = 8MHz
λ_o = 38m
THEORETICAL
D = 3.0 λ
K_I = 3.2
tan δ = 0.03
DISTANCE FROM SOURCE IN FREE SPACE WAVELENGTHS (λ_o)
0
2
4
6
8
10
12
14
16
18
FIELD STRENGTH
H_ρ

Figure II-14

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II-4. EXPERIMENT APPROACH

A. Experiment concept

The basic concept of the experiment is very simple. A transmitting antenna is set up on the surface that is to be probed, and a receiver is moved over the surface at some distance from the transmitter. As shown in Figure II-15, there are at least two waves which reach the receiver: a direct wave along the surface and a reflected wave from the subsurface.

In general, these two waves travel different distances at different velocities and therefore interfere with each other. In some cases, the interference is destructive, in others, constructive. The result is a series of peaks and nulls in the received field strength as the separation between the receiver and the transmitter is changed. It is this interference pattern of peaks and nulls which is indicative of the electrical properties of the medium and of the depth to the reflector.

In practice the situation is not quite so simple. There are, in fact, a number of different waves generated. As shown by Figure II-16, there are two spherical waves, A and C, travelling directly between the transmitter and the receiver. Wave C travels in the upper medium and wave A in the earth. Since these two waves have different velocities, they will interfere with each other. It is this interference which

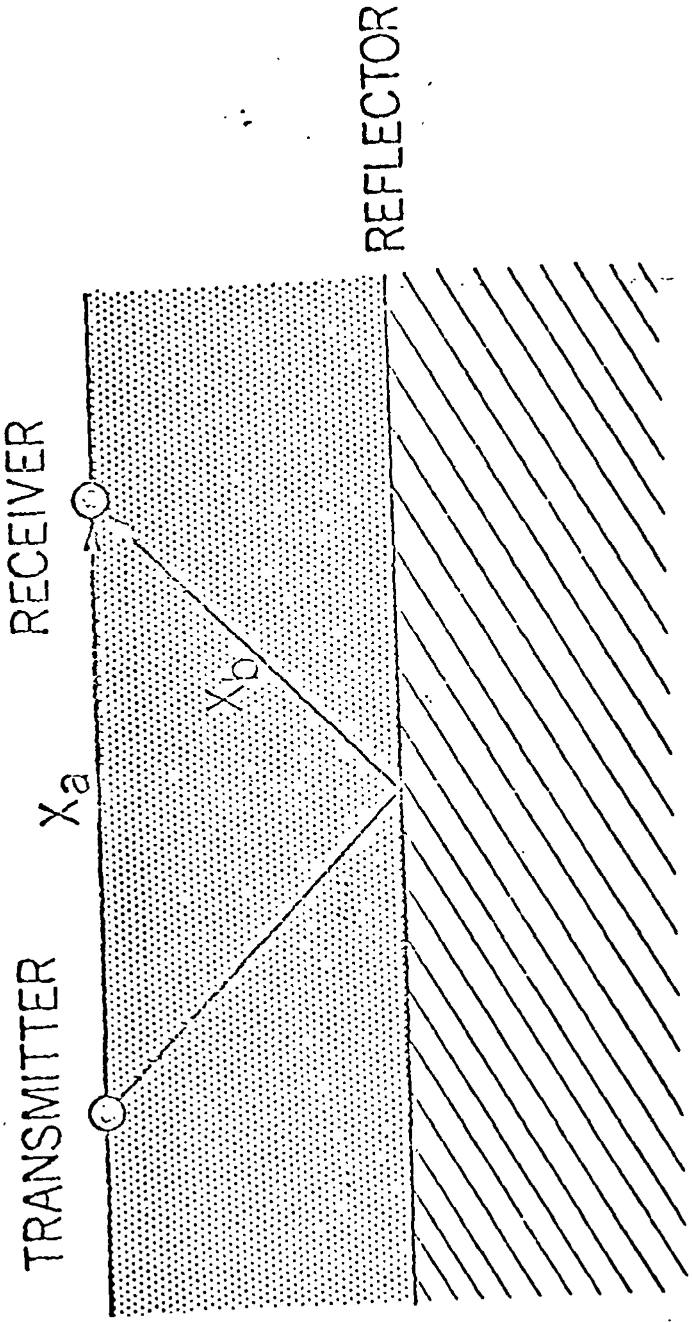
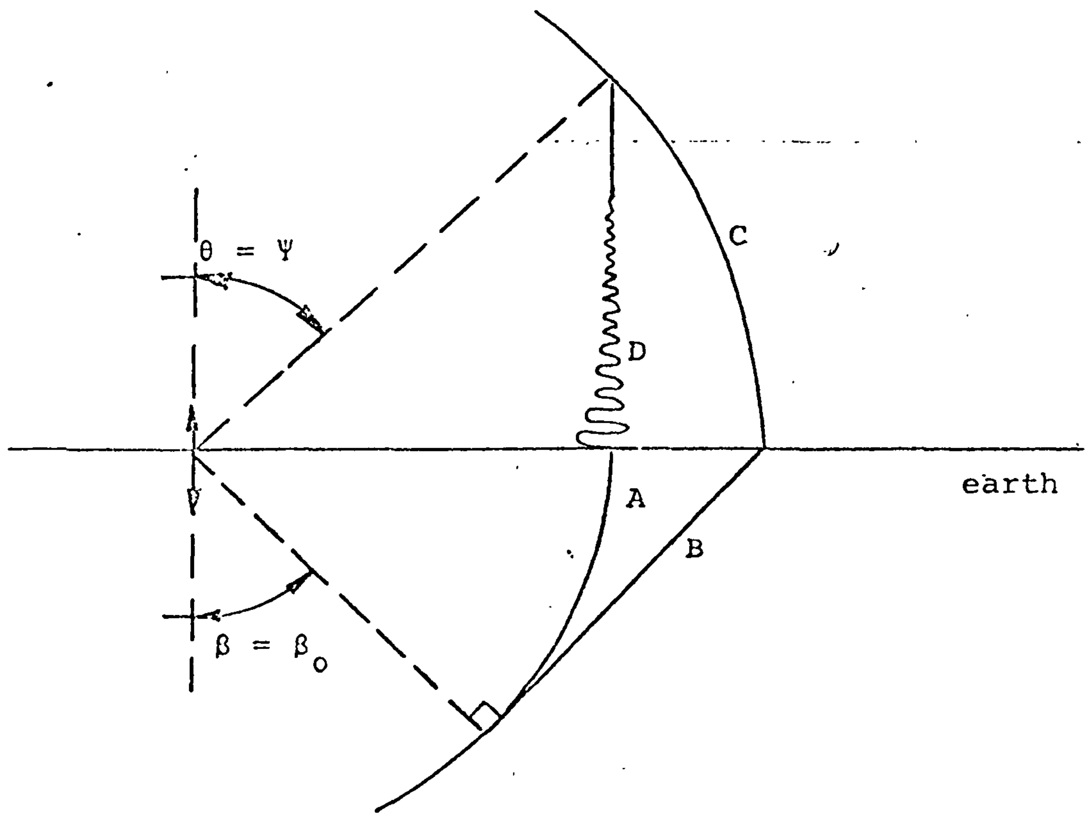


Figure II-15: Basic Experiment Concept.



A - spherical wave in earth

B - flank or head wave in earth

C - spherical wave in air or vacuum

D - inhomogeneous wave in air or vacuum

Figure II-16: SKETCH OF WAVEFRONTS AT THE AIR-EARTH INTERFACE gives a measure of the dielectric constant of the lower medium, since the greater the difference in the velocities of these two waves, the greater will be their rate of interference.

Another wave of some importance is the flank, or "head", wave, B. This wave is responsible for the directionality of the antenna pattern below the surface. It develops in order to satisfy the boundary conditions of wave C at the interface, since the phase velocity of some wave in the earth must be the same as the phase velocity of wave C, in the upper medium. This condition is satisfied if plane wave B propagates downward to some extent. The tilt is given as β, the angle of total internal reflection between the two media. Hence, $\sin \beta = \sqrt{\frac{E_o}{E_1}}$, where β is the angle between the z-axis and the direction of the wave, and $\frac{E_o}{E_1}$ is the ratio of refractive indices across the boundary. The importance of this wave is that it effectively gives the antenna radiation pattern a lobe at angle β.

The spherical wave A, travelling in the lower medium, also matches the boundary conditions, but in a different way. An inhomogeneous wave, D, is produced at the surface; this wave is directed upwards and decays exponentially with height above the surface. This wave is not as significant as the others discussed above.

Evidently, the practical usefulness of this method for depth sounding depends upon two major implicit assumptions. First, the medium being probed must not be too lossy or the amplitude of the reflected wave will be too low to interfere well with the direct waves. Second, there must exist some strong electric contrast below the subsurface or there will be very little energy reflected.

It has been shown previously that the lunar surface should be very transparent to radio waves. The contrast necessary for reflecting energy from depth could come from a change in dielectric properties, electrical conductivity or density. A range of frequencies, with wavelengths from 10 meters to 600 meters, is planned since these wavelengths correspond to the range of depths under consideration. Hence there is little fear that these conditions will not be met on the moon.

Interpretation of the data evidently requires a knowledge of the location of the receiver relative to the transmitting antenna. Position determination will be done in this experiment by determining a distance at an azimuth.

Two crossed transmitting antennas will be driven with differing modulations in such a way that first one antenna will be powered and then the other. This has the effect of making the radiation pattern rotate. The transmitter will radiate a sequence of eight discrete frequencies used in the experiment; switching between these frequencies will be synchronized to provide a time base. Since azimuth determination can be done at several frequencies, the problems of multipath and beam distortion can be sorted out and, therefore, it is expected that accurate directions can be determined in this way.

The second part of the system will consist of analysis of the field strengths to give distance from the source. In general, the received field strength will be inversely proportional to the distance from the source and so, in general, can be used to determine the distance. Although any individual observation may be disturbed significantly by interference, the data can be averaged readily to give smooth curves. Moreover, this can be done using many frequencies so that there is inherent redundancy in the system.

It is presently planned that, as part of the traverse, the astronaut will walk along one arm of the transmitter antenna, locating himself precisely by means of markers along the antenna. This will give location data for the high frequencies where precision is required, and also will serve to calibrate the ranging system.

The use of these two approaches is expected to locate the receiver system at all times with the required accuracy. At greater distances along the traverse, the low frequencies are of most interest so that the accuracy required in position decreases as the astronaut moves away from the transmitter. Internal checks using several frequencies will be available and the use of smoothing along the path will be most helpful.

B. Experiment Procedure

A schematic diagram of the procedure is shown in Figure II-17. The source will be a center-fed half-wave dipole antenna laid on the surface near the LM. It will be powered by a small transmitter producing continuous waves at discrete frequencies of 0.5, 1, 2, 4, 8, 16, 24, and 32 MHz successively. This sequence will be repeated once per second. As described previously, another identical antenna will be laid out at right angles to the source antenna so that a rotating radiation pattern can be created for the purpose of azimuth determination.

The receiving antenna will consist of one, two or three orthogonal coils about one foot in diameter. These will detect the three orthogonal components of the received field at each successive frequency. The strength of the three field components will be recorded separately on a small tape recorder. The recorded information will be returned to earth for data analysis.

It is anticipated that the receiving coil will be attached to the MET or to the Lunar Rover. Initially, the astronaut will have to deploy the transmitter and associated dipole antennas. The astronaut then will move away from the transmitter in a direction that is roughly perpendicular to one of the, identical, dipoles but will not be constrained to walk in a straight line. A traverse to a distance of 3 km or more is desirable, but shorter distances also can yield useful data at the higher frequencies.

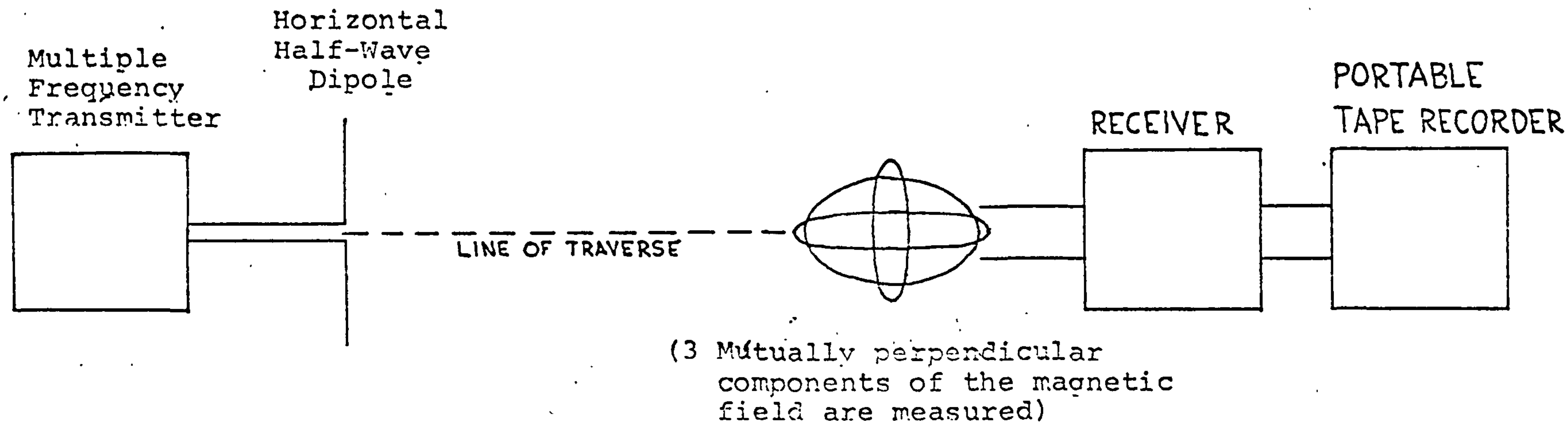


Figure II-17 Layout of Basic Experiment

During the first stages of the traverse, the most useful data will be that derived from the highest frequencies and, since the position of the receiver must be known within about one-fifth of a wavelength, an initial accuracy in position of about two meters is necessary. This will be achieved by having the astronaut walk along any one arm of the antenna, which will be marked with fixed distance points, either pausing for about one second at each marked point or reading his position into the voice record. This procedure also will calibrate the ranging system.

During the remainder of the traverse, although it is desirable that the astronaut travel approximately perpendicular to one of the transmitting dipoles, this is not critical. He will be free to roam anywhere in a sector of about 20 degrees, and entirely free to conduct other studies and activities. The range information also is not so critical at greater distances so, after the initial stages, the experiment will require only a minimal amount of astronaut attention.

It is necessary to record information on both the vertical and horizontal magnetic fields at each point. Since these two fields create independent interference patterns, interpretation ambiguities will be reduced by having both fields recorded separately. Since the horizontal field propagates in a radial direction from the transmitter, it is not necessary to orient the receiver precisely with respect to the transmitter; it is only necessary that the plane of one coil be approximately horizontal. However, if the coils could be aimed roughly (say within ± 5 degrees) occasionally during the traverse, and so noted by the astronaut on the voice record, additional information that would be a useful estimate of the amount of lateral inhomogeneity could be made.

The above operating procedure has been determined largely on the basis of field trials made on glaciers. A one watt engineering breadboard of the proposed transmitter, constructed by the M.I.T. Center for Space Research, was used to feed a tuned ribbon wire half-wave dipole antenna. Receiver coils of one and three feet diameter were used with a commercial Galaxy R530 communications receiver.

Tests on the Athabasca Glacier, Alberta, gave results typified by Figures II-18 to II-20. Agreement between theory and data is not perfect for several reasons. First, the theoretical solutions are approximate, due to the mathematical complexities. Second, they are for an infinite, plane, horizontal, layer, which the glacier is not because it has sloping interfaces. And third, some scattering is probably present in the field data. Nevertheless, the general shape of the curves is reasonably good, giving a depth to the bottom of the glacier of about 150 meters. This agrees completely with previously published seismic and gravity results of several workers.

Frequencies of 2, 4, 8, 16, and 24 MHz were used. Although the results for the lower frequencies were tolerably noise free, those for the higher frequencies showed a large

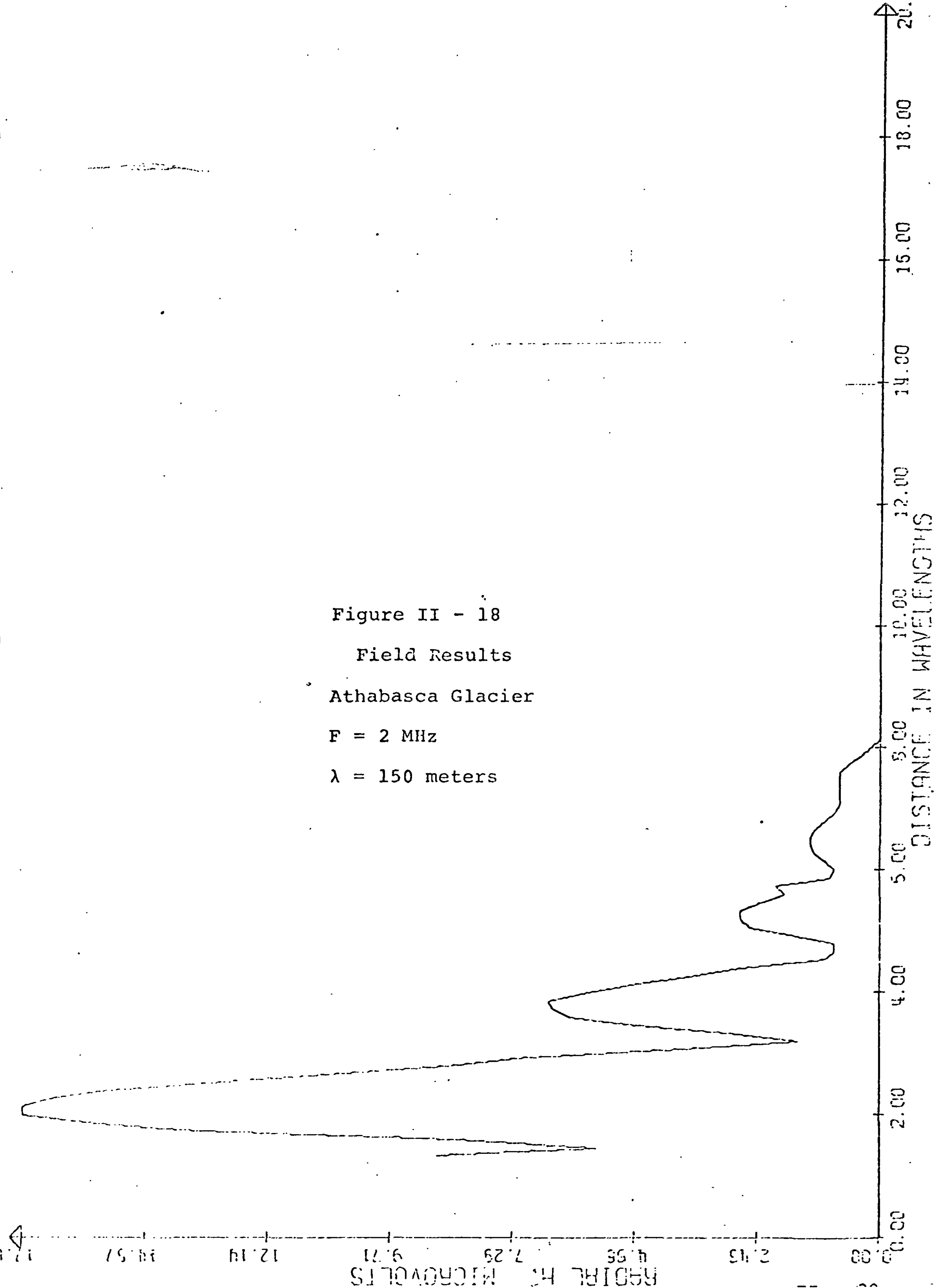


Figure II - 18

Field Results

Athabasca Glacier

F = 2 MHz

λ = 150 meters

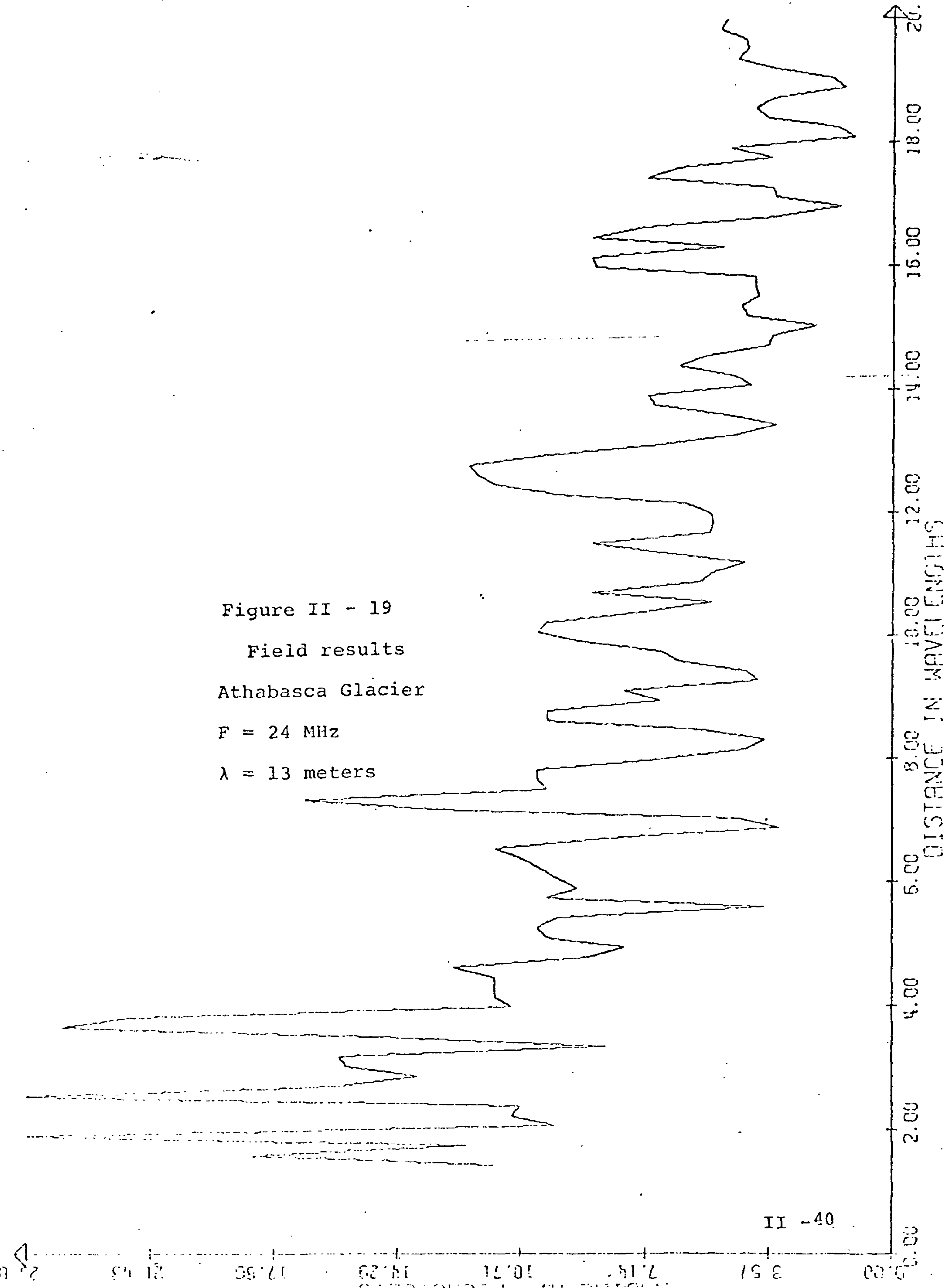


Figure II - 19

Field results

Athabasca Glacier

F = 24 MHz

λ = 13 meters

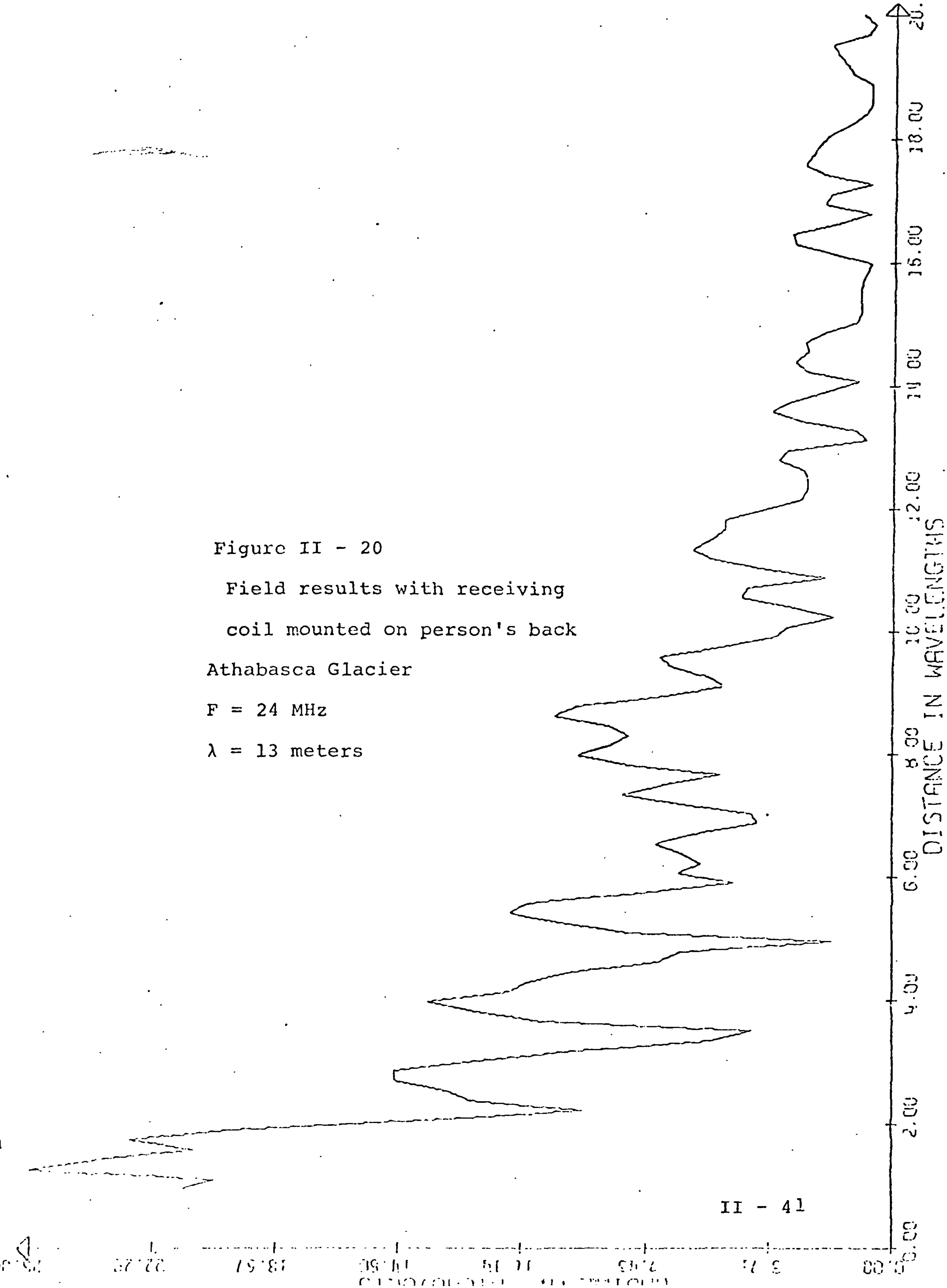


Figure II - 20

Field results with receiving coil mounted on person's back

Athabasca Glacier

F = 24 MHz

λ = 13 meters

amount of scattered energy. This is probably because irregularities are approximately the same size as the wavelengths of the higher frequencies. The rapid changes of the field strength with position make it necessary to sample the field at least every one-fifth of a wavelength.

Studies were also made with the one-foot antenna strapped on a person's back. Although the interference of the human body was greatest at the higher frequencies, the results of this test are not dissimilar to the others (compare Figures II-19 and II-20).

Although this trip gave satisfactory results, much remains to be done. Only by field trips can the optimum procedure for taking measurements be determined. Moreover, the problem of scattering requires more study. As an engineering field model and prototype instruments are developed, they must be tested in the field without delay.

C. Quantitative range of the measurements

During the traverse, various measurements will be made continuously and recorded automatically on tape. The basic data are the strengths of two independent components of the horizontal magnetic field, and the vertical field. Eight frequencies between 0.5 and 32 MHz will be monitored for the duration of the traverse, with a complete sequence of the eight discrete frequencies repeating once per second. Time also will be recorded on the magnetic tape.

The dynamic range of possible values for the field strengths is quite large, due to the large oscillations imposed by the interference technique. Moreover, some of the most useful information can be obtained when the received signal is relatively small, and the values depend on the electrical properties of the lunar subsurface. Field measurements made over glaciers indicate that the probable range of values of interest at the receiving antenna is from 20 to 0.01 microvolts/meter. This should be measured with an accuracy of about one percent.

The distance between the receiver and the transmitter is expected to range from zero to about 6000 meters, or more if the Rover vehicle is used. For all signal frequencies, it is necessary to know the position to approximately one-fifth of a wavelength. However, the higher frequencies are only useful nearer the transmitter, while the lower frequencies are of principal interest further away. Therefore, the ranging measurement will have to be more accurate near the transmitter than it will at a large distance. Near the source, the astronaut can use the distance indicators marked on the antenna arms and read his distance into the voice record. For the remainder of the traverse, azimuth and distance information will be provided by the data themselves. A good estimate of the accuracy needed is about one percent of the actual distance.

D. Method for analysis and interpretation of data

Analysis of the data will take several steps. First, the receiver location data must be translated from a bearing measurement and range to position versus time information. It is anticipated that this will require combining data from the voice record and photographs, as well as from the experiment itself. The field strengths which will already be in a measurement versus time format then can be converted to field strength versus position. The vertical component will be complete, and the radial component will be the vector sum of the two horizontal components.

Once the information is in this form, it can be compared to standard curves computed for a large number of expected conditions. The problem of a horizontal electric dipole on the surface of a dielectric layer has been tackled theoretically for several cases of interest. The half-space case (i.e. virtually no reflected energy from depth) still gives an interference pattern, and this has been worked out rigorously for both the H_z and H_ρ components. The layered case is not so simple. Approximate solutions have been obtained, for both components, for the case of a dielectric layer underlain by a horizontal reflecting layer. Families of solutions are being computed for arbitrary losses, dielectric constant, and depth of the first layer. A few examples of these curves have been shown previously in Figures II-3 to II-10.

Many important cases remain unsolved; they must be studied before satisfactory interpretation of the data from the moon can be assured. Examples are the cases of sloping interfaces, arbitrary changes in dielectric properties, more than two layers, etc. The effect of curvature of the moon's surface also is important for the longer wavelengths and distances. Some of these problems are presently being tackled theoretically.

However, it is likely that few of these problems will yield even approximate theoretical solutions. For this reason scale-model studies must be an essential part of the interpretation program. A model already has been used successfully to confirm theoretical studies, and to aid interpretation of field results. A new model is being constructed which will overcome some of the limitations of the previous one.

The new model will consist of a large bath of transformer oil of carefully controlled dielectric properties, and a 5 cm. wavelength electric dipole source. The tank will be anechoic for microwave frequencies, and will allow easy measurement of many different subsurface configurations. In addition, the radiation pattern of the antenna can be measured in the dielectric medium, which will aid in theoretical studies.

One of the most interesting problems to be modelled in the tank will be the effect of scattering bodies in the subsurface. Scattering effects have been seen in field data, and lunar seismic data indicate that they could be very important on the moon. Therefore, any information on position, surface topography, and coil orientation that the astronaut can supply will be useful in interpreting these effects.

Another aspect of interpretation is the possibility of computerizing the procedure. This may be accomplished by evaluating several critical parameters, such as the dielectric constant, from a set of data, and then allowing the computer to search for the best fit from many theoretical models. Another approach will be to analyze harmonically, then to filter the data digitally looking for characteristic frequencies. This might be essential if a large amount of scattered energy is present.

Further studies of the dielectric properties of lunar samples also should be made. This is important to determine the range of likely cases that may be encountered on the moon.

Above all, the various methods of interpretation must be evaluated on real data. This can come only from field measurements using the types of apparatus that will be used on the moon. As field trial models become available, they must be evaluated without delay. Field work must proceed in conjunction with all other aspects of the project.

E. Prime obstacles or uncertainties which can be anticipated

The experiment is conceptually simple and uses electronic equipment that is scarcely more complicated than a conventional FM transmitter and receiver. The chief uncertainties are associated with an adequate determination of the astronaut's position during the traverse, and interpretation of the effects of subsurface inhomogeneities.

Most ranging systems on earth use electromagnetic radiation of some nature to monitor location. However, there are drawbacks to this type of system on the moon. If high frequency radiation such as a laser beam is used, the astronaut will soon get out of line of sight due to the curvature of the lunar surface or to surface obstacles such as craters. On the other hand, lower frequencies, which will propagate along the surface, also will propagate downward and suffer reflection from the subsurface. Thus the traditional problem of multipath is inherent in the lunar surface.

To compensate for these problems, position determination will be done using several transmitted frequencies to give an azimuthal bearing and a range. The lower frequencies should give satisfactory operation beyond the line of sight, and the use of many widely spaced frequencies should permit an evaluation of the multipath problems.

Not only the ranging system is affected by inhomogeneities. The experiment itself, like virtually all geophysical techniques, is inherently ambiguous. Although good interpretation of the data is, of course, possible, the large number of unknown parameters may lead to several possible solutions for a given set of data. This problem will be complicated by random scattering from surface, interface, or subsurface irregularities. Because of this, any information that the astronaut can give on surface features or receiving coil orientation will be useful.

The fact that the experiment uses a large range of discrete frequencies is a beneficial factor. It is not expected that scattering bodies very much larger, or very much smaller, than a particular wavelength will affect that frequency unpredictably. Therefore, although a few frequencies may be adversely affected by random scatter, it is unlikely that they will all be affected simultaneously. And the very fact that a certain wavelength is prone to scatter itself gives useful information on the nature of the subsurface.

Neither of these problems is trivial; both are being studied intensively at the present time. These studies must continue in conjunction with the construction of apparatus. Prototype apparatus must be tested in the field to obtain additional data. Scale-model studies, in which conditions can be carefully controlled, will yield important clues to the effects of scattering.

F. Significance of the astronaut

The astronaut has several important duties in this experiment. He must choose the optimum site for deployment of the transmitter and transmitting antennas, avoiding large obstacles such as rocks or craters. He must transport the receiver and tape recorder along one arm of the antenna to give accurate position information at the beginning of the traverse. He must then mount the receiver on the MET or Rover before starting on the long traverse.

It would be very desirable to deploy the transmitting antennas so that the long traverse is constrained to a sector of about 20 degrees normal to either one of the crossed dipoles. Also, if the astronaut occasionally could orient the receiving coils with respect to the transmitting antenna and record that he is doing so, additional useful information on the subsurface inhomogeneities would be obtained. Of course, any information on surface topography would aid in interpreting scatter and in checking the receiver location.

Apart from these considerations, the experiment requires minimal attention from the astronaut and will leave him free to perform any other duties.

II-5. BASELINE OR CONTROL DATA

The major support that will be needed during the post-flight data analysis is all available data on the position of the receiver during the traverse. This information may come from a variety of sources. Although the experiment inherently includes a position determining capability, this information may be incomplete or ambiguous due to the nature of the lunar surface. Therefore, any information the astronaut can put on the voice record will be useful. This is particularly true during the initial stages of the traverse. It is expected that surface photographs also will yield helpful position information.

A knowledge of the surface topography along the traverse also would be useful. This information will come from surface photographs that can be tied in with orbital photographic work. Again, any information on the voice record will be helpful. Once the position and surface information during the EVA have been calculated, they will be available to all other experimenters, of course.

SECTION III - SUMMARY DESCRIPTION OF KEY RESPONSIBILITIES, SUPPORT AREAS AND TASKS

III-1. Organization and Responsibilities

The Principal Investigator is responsible for all science and science-related aspects of this program as described in Section 2.0 (technical) and 3.0 (management) of "Exhibit C -- "Surface Electrical Properties Experiment, Principal Investigator Statement of Work," dated September 1, 1970.

The team effort approach described here in Section 1.2, along with unique requirements of the SEP experiment, necessitates substantial technical support for the Principal Investigator. It is the responsibility of personnel connected with the M.I.T. Center for Space Research to render this support and to assist both the PI and MSC in the science and engineering management of the experiment as outlined in Exhibit C.

III-2. Support Areas and Tasks: Summary

The principal area for support and the related job functions are described below. This breakdown is consistent with the statement of work, and serves only to describe better the problem areas associated with this experiment and, importantly, as a cross reference for cost analysis. The support areas are:

A. Direct Support of MSC

1. Attend all significatn meetings as necessary to represent the PI and assist the science manager and the engineering manager.

2. Periodical and timely reports, both verbal and written, to the MSC science manager and engineering manager.

3. Advise the science and engineering managers in matters related to the technical issues such as experiment configuration trade-offs, hardware requirements, etc.

B. Direct Engineering Support of the PI, PA and Other Scientific Staff and M.I.T. and the University of Toronto

1. Keep the Principal Investigator and Principal Administrator at M.I.T. and MSC informed on all matters of principal importance. This will particularly apply to the engineering in the following ways:

a. Notify those involved if the quality or quantity of the science data is compromised;

b. Advise on data processing and experiment calibration procedures;

c. Coordinate the dissemination of information from various theoretical analyses, field test data, laboratory test data, etc.

2. In the area of experimental operation procedures, advise on the calibration procedures to be used on the lunar surface at KSC and on the glacier trials. These procedures must be identified in detail and related to hardware calibration in a rigorous and meaningful way.

3. Field tests: Conduct and reduce the data from tests of engineering and prototype models as well as calibration of the flight spare.

4. Assist in pre- and post-flight analyses as required.

5. Provide assistance to the PI in overall coordination of the science effort through writing applicable memos and progress reports. Also, assist in the organization of information flow between

the PI, PMO (at M.I.T., University of Toronto, MSC) and the hardware contractor.

6. Develop and fabricate experiment test hardware as needed for field trials, analog models, antenna range calibration tests and support of experiment studies.

C. <u>Direct Support of PMO in Coordination and Control of Experimental Hardware Fabrication and Test</u>

1. Assist in and advise on the technical monitoring of the experiment hardware contractor and/or subcontractors as required.

2. Periodical reports and special notes of significant issues.

3. Participation in formal design reviews.

4. Assist in Quality Assurance monitoring, especially in those areas where LSE has unique expertise; for example, high voltage and/or RF corona problems.

SECTION IV - SURFACE ELECTRICAL PROPERTIES EXPERIMENT (S-204)

STATEMENT OF WORK

IV-1. Science Objectives

To determine layering in the lunar subsurface

To search for the presence of water in the lunar interior

To measure lunar material electrical properties in situ

To obtain an independent estimate of the lunar surface thermal flux

IV-2. Science Requirements

* Transmitter and antenna will be deployed about (at least) 150 meters from the LM

Receiver will be carried (astronaut or LRV) along a traverse which starts at the transmitter/antenna and extends to a maximum of 1 to 10 km

* Receiver will record data on magnetic tape during the EVA. Magnetic tape retrieved from receiver and returned in mumetal container.

* Timing data to be supplied by experiment permitting post-flight definition of range accurate to about one percent of range

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* Denotes a change from that of Exhibit C, SEP Experiment PI Statement of Work, September 1970.

IV-3. Purpose

The purpose of this statement of work is to define those services to be performed by the Principal Investigator (PI) for the scientific support of the Surface Electrical Properties Experiment (SEP). Generally, these services will pertain to the support required to develop the experiment hardware, to the effort required to integrate the experiment into the Apollo program, and for the support for the scientific analysis, interpretation, and reporting of the data obtained from the experiment.

IV-4. Technical

A. Technical Support

1. Scientific requirements. The PI shall establish the scientific requirements and the objectives for the SEP experiment and shall participate in the design, performance, and operation of the flight instrument. The PI shall likewise evaluate all instrument specifications, changes, and modifications to insure that the scientific objectives and requirements from the experiment will not be compromised and shall provide the results of such evaluation to NASA/MSC.

2. Technical support for hardware

a. Instrument hardware support. The PI shall assist NASA/MSC when technical and scientific guidance is required for the SEP experiment hardware. In particular, the PI shall support the SEP Experiment Manager in these areas and efforts that pertain to the design, development, and fabrication of the instrument hardware. These duties shall include, but not be limited by, the following:

(1) Review and approval of Type I documentation on the SEP, including such items as end-item specifications, test plans, interface control documents (ICD's).

(2) Participate in the design and development of the SEP and associated GSE.

(3) Participate in formal design reviews, monthly meetings, and other special meetings convened to discuss the instrument hardware.

(4) Assist the integration contractors in establishing requirements for ICD's.

(5) Participate in the instrument preacceptance and calibration testing and integration testing of SEP.

b. KSC support. The PI shall support any effort requiring his presence at Kennedy Space Center. This support shall include assisting in verifying that instrument performance is acceptable in meeting the scientific objectives and requirements of the experiment.

3. <u>Premission and mission support</u>

a. Mission planning. The PI shall assist NASA/MSC in mission planning activities related to the SEP experiment. The mission planning activities shall include, but not be limited to: operating modes, contingency modes, supplemental supporting data requirements, and deployment requirements.

b. Surface science working panel. The PI, as required, shall assist NASA/MSC and, in particular, the SEP Science Manager by attending or providing scientific requirements and/or scientific guidance in support of the Surface Science Working Panel meetings.

c. Mission support. The PI shall assist NASA/MSC during and after the mission in providing guidance concerning experiment operation, quick-look data analysis, and assist the Operations and Data Management Office (TM5) in the preparation of the mission reports such as: Apollo daily report, Apollo mission five-day report, 30-day failure and anomaly listing report, and the Apollo mission report.

4. Co-investigators

The PI shall be responsible for establishing the tasks to be accomplished by his co-investigators. The PI shall be responsible for organizing the efforts and management of all relations with his co-investigators. Any delegation of authority to the co-investigators by the PI will be done at the discretion of the PI and on an as-required basis. These tasks when defined will then become part of this statement of work.

B. Supporting Studies

The PI shall establish all studies required in support of the SEP, the objectives of these studies, the relationship of these studies to the primary experiment, and the manner in which they are to be conducted. The supporting studies so identified shall include and outline those tasks to be accomplished by both the PI and his co-investigators. The supporting studies, when they are approved by NASA/MSC, shall be incorporated herein and become a part of this statement of work. The PI shall prepare reports which describe the results and analyses of the studies and these reports shall be submitted to NASA/MSC as part of the progress report.

The PI shall be able to identify all required supporting studies and report within three months after contractor award. At the present time, however, it is evident that considerable study effort will be required in the area of data interpretation. These studies will require both laboratory monitoring work at higher frequencies and glacier signature studies (trials) with prototype experiment equipment. Further, both of these areas will need to be studied for varying experiment conditions simulating a wide range of dilectric conditions, that is, varying dilectric constants, loss tangent, layering, multipath, degree of inhomogeneity, etc. as a function of (at each) experiment frequencies. Our cost estimates attempt to reflect accurately the complexities of these studies.

C. Supporting Equipment and Facilities Requirement

The Principal Investigator shall identify any additional equipment and facilities that may be necessary to the development of the experiment. The PI shall identify the methods and organizations/agencies to be used in the procurement of acquirement of such equipment and/or facilities; e.g., new procurement by PI, GFE, government-owned by NASA/MSC, etc.

** Explanatory statement intended for information purposes.

All such requirements shall be organized into a plan by the PI and then shall be subsequently submitted to NASA/MSC for approval. After final approvals have been obtained, this plan will become a portion of this statement of work.

D. Scientific Data Reduction and Analysis

The PI shall prepare and submit a plan identifying each phase of the data reduction and analysis program. This plan, when approved by NASA/MSC, will become a portion of this statement of work. Items 1, 2 and 3 to follow shall be listed separately and included in the data reduction plan.

The PI shall support and participate in, where necessary, the data reduction and analysis activities specified for the experiment as described in the approved data reduction and analysis plan.

1. Computer programs

The PI shall include, as a part of the overall data reduction and analysis plan, a computer plan that identifies computer requirements which are necessary to the execution of the overall plan. This subplan shall include, as separate items, computer time and programming support to be provided by either subcontract, MSC, or through the PI's parent organization.

The PI shall provide all computer programs required by MSC or by the PI for all activities concerned with data reduction.

2. <u>Data processing and formatting requirements</u>

The PI shall identify, in the overall data reduction plan, each phase of the data reduction process and also shall identify all subcontracted efforts as separate items. The necessary formats required for data reduction shall be described.

The PI shall be specific in the data processing plan as to the requirements to be imposed upon organizations within MSC and in other agencies that would become involved with the processing and reduction of data, the manner in which data distribution is to be made, the number of copies and types of data required, formats for processed data, the supporting data required, etc.

The PI shall identify all types and formats of data that MSC is to supply to the PI in support of his contractual effort. All such requirements will comprise a portion of the Scientific Data Reduction and Analysis Plan to be submitted to NASA/MSC within six months after contract initiation.

3. <u>Data interpretation</u>

The PI shall be solely responsible for the scientific merit, technical analysis, and interpretation of data obtained from the SEP experiment. In achieving this end, he shall be responsible for the management of all personnel under his direction and the allocation of resources as concerned with this effort to insure the accomplishment of the scientific objectives related to this experiment.

IV-5. Management

A. Management Relationship

The NASA/MSC is the management agency for the SEP experiment instrument and the experiment PI services contract. At MSC, the Experiment Manager shall be the source of all technical direction for the instrument hardware, and the Science Manager shall be the source of all PI related efforts. The PI shall provide technical and scientific guidance on matters related to the design and performance of the SEP and may, when required, initiate technical direction concerning the instrument hardware through MSC channels accessible to either the Science or Experiment Manager.* MSC, through the Experiment Manager, will implement the PI's requirements and/or direction on matters related to the SEP experiment hardware when consistent with cost, schedule, and interface constraints.

B. Management Reporting

1. Monthly progress reports

The PI shall submit monthly progress reports of all work accomplished during each month of contract performance. Reports shall be submitted in narrative form and be brief and informal in content. Reports shall include, as a minimum, a discussion of the following items:

a. Summary outlook for the remaining effort to be performed.

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*This is one of the support efforts in which CSR will play a vital role.

b. Overall status, including problem areas and significant progress to date.

c. Expected accomplishments during the next reporting period.

d. Recommendations as to decisions and/or actions required to insure attainment of the experiment scientific objectives.

2. Financial management reports

The PI shall submit monthly financial management reports in accordance with the procedures of NHB 9501.2, Procedures for Reporting Cost Information, dated March 1967. Appendix D of this handbook, entitled "Contractor Remarks," shall be utilized when variances are in excess of $\pm$ 10 percent.

D. Data Analysis Reporting

1. Apollo preliminary science report

The PI shall prepare an interim experiments report after the mission concerning the SEP. The report shall describe the experiment, objectives, and the data reduction/interpretation techniques in use. Preliminary conclusions that can be deduced from the experiment shall also be presented. This report shall be submitted to the Operations and Data Management Office (NASA/TM5) approximately 50 days after astronaut recovery. (Note that the cost estimates reflect the need to perform a post-flight data storage test on a glacier with the "returned tape unit.")

2. <u>Experiment final report</u>

The PI shall prepare a final experiment report for submission to NASA. The report will be based on previously prepared papers and should include a brief description of the experiment and its objectives, anticipated results correlated with results obtained, conclusions reached, and a final summation of the complete experiment. Final experiment reports will normally be submitted one year from crew recovery of the applicable Apollo mission.

3. <u>Final contract report</u>

The PI shall submit a final report which documents and summarizes the results of the complete contractual effort. Included are to be recommendations and conclusions based upon the experience and results obtained. This report shall contain all necessary calculations, charts, photographs, and drawings in sufficient detail as to explain comprehensively the results achieved during the contract period.

This report shall be submitted after the end of the final mission utilizing this experiment as a portion of its scientific payload. The time for submittal of this report will be negotiated with the PI. The report when submitted should be in such a form as to be suitable for publication in scientific journals.

D. Report Delivery Schedule

Item	Delivery Date
Supporting Studies Plan	3 copies due 3 months after contract award
Supporting Equipment and Facilities	3 copies due 3 months after contract award
Science Data Reduction and Analysis Plan	3 copies due 6 months after contract award
Progress Reports	3 copies by the 25th of the month
Financial Management Reports	4 copies by the 25th of the month
Review of Instrument Contractor ICD's and Related Technical Matters	5 days after receipt of ICD, etc.
Apollo Preliminary Science Report	4 copies plus one reproducible copy 50 days after the end of mission
Experiment Final Report	4 copies plus one reproducible copy one year after the end of mission
Final Contract Report	4 copies plus one reproducible copy about one year following the final mission in the experiment series (exact time to be negotiated)

E-2509

NASA EXPERIMENTS CONFIGURATION MANAGEMENT PLAN

by

M. G. Murley

August, 1970

Type I Document
NASA Approval Pending

CHARLES STARK DRAPER LABORATORY

CAMBRIDGE, MASSACHUSETTS, 02139

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NASA EXPERIMENTS CONFIGURATION MANAGEMENT PLAN

by

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August, 1970

CHARLES STARK DRAPER LABORATORY
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L.E. LARSON, DEPUTY ASSOCIATE DIRECTOR
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Approved: D. G. Hoag Date: 28 Sep 70
D.G. HOAG, ASSOCIATE DIRECTOR
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Approved: Ralph R. Ragan Date: 28 Sept 70
R.R. RAGAN, DEPUTY DIRECTOR
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INTRODUCTION

CONFIGURATION MANAGEMENT PLAN

Purpose

This document presents the CSDL plan for the establishment, implementation and maintenance of a configuration management system for NASA experiments.

It provides an operating plan and the necessary procedures to provide a common base for configuration management.

Organization and Function, Configuration Management Office

The objective of this document is to outline the overall functional organization of Configuration Management for NASA Experiments and to specify its responsibilities and basic authority. The CMO operates in a management capacity to identify the requirements, establish the procedures and assign responsibility for the establishment and maintenance of configuration control for NASA experiments and their related support equipment.

The following formally organized boards provide the basic coordination and control points for configuration management.

(1) Design Review Board (DRB)

(2) Configuration Control Board (CCB)

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CHAPTER 1

DESIGN REVIEW BOARD

DRB Organization and Procedures

1.1 Purpose

This Chapter defines in sufficient detail the Design Review activity undertaken by CSDL in connection with the design and development of NASA experiments and short term programs.

The concept is to provide the highest degree of assurance as early as possible so that maximum potential is realized for the design factors below, and any areas requiring additional improvement may be defined and acted upon in an expeditious manner. The intent is to make the DRB a beneficial endeavor to all concerned with the design of the experiment and its interface with associated systems. The degree of success depends on the attitude and cooperation it is afforded.

In each element of design the following factors are to be considered:

Reliability	Failure Effect Analysis
Producibility	Standarization
Maintainability	Optimization
Compatibility	Function and Operability
Interfaces	Parts Application
Material Usage	Mechanical Integrity
Safety	Cost
Format	Completeness

1.2 Scope

The Design Review shall be applicable to all initial design and engineering efforts. All documents describing the design of the experiment or important to its fabrication, assembly, test, use, and procurement of parts and material must be reviewed and approved by the DRB before submittal to and release by the CCB. In changes subsequent to Design

Review and Change Control Action, not effecting Reliability, Form, Fit or Function, that is to say, Class II changes (as defined in Section 2.7) need not go to Design Review, only to the Change Control Board.

1.3 Function

The Design Review will bring together representatives with specialized as well as general experience to evaluate the detail design for consideration of factors as aforementioned. Although the responsibility for design will continue to be that of the design engineer and no attempt will be made by Design Review Representatives to usurp the prerogatives of the designer, they can and will, by an unbiased and independent appraisal, assure that every consideration has been given toward the generation of an optimum design. Courses of action necessary to alleviate or correct any hazard areas will be recognized and implemented before costly malfunctions can be experienced. The result of Design Reviews will be adequately documented to ensure effective follow-up corrective action.

In order to realize the full benefit of the Design Review, it must take place in sufficient time to permit any corrective measures developed to be incorporated before release through the CCB. While it is highly desirable for the DRB to consider the design package in the final form in which it will be released, and every effort should be made to permit this, it is recognized that because of overall schedules and the need for releasing designs to start fabrication and procurement, such may be neither possible nor practical. It is far better to conduct a timely review on preliminary versions of the final design that may be nearly complete than to wait until everything is complete and no time is left for adoption of beneficial recommendations stemming from the Design Review.

Therefore, design groups shall carefully weigh their progress against release deadlines and suggest that the design reviews be scheduled at the earliest possible time that meaningful results can be obtained.

1.4 Organization

The DRB organization and individual responsibilities are as follows.

1.4.1 Representation

Chairman	:	Project Technical Director (or Designate)
Recorder	:	Secretary Clerk
Member	:	System Integration Staff Engineer
Member	:	Responsible Design Engineer
Member	:	Manufacturing Engineer
Member	:	Quality Assurance/Reliability Engineer
Others	:	Consultants as required

1.4.2 Responsibilities

Chairman

(1) Preside at DRB Meetings.

(2) Provide DRB signature approval of an Engineering Change or Release (ECR).

Recorder

(1) Assist Chairman in scheduling Design Review Meetings.

(2) Determine scope of each review and notify particular members of date, time, place, subject and materials required.

(3) Keep an accurate record of proceedings.

(4) Maintain records and file of Design Review activities, prepare and distribute reports.

Members

(1) Participate in reviews.

(2) Present descriptions of the design or proposed changes thereto, reasons for the change along with any data and results of engineering evaluation as required.

(3) Act on recommendation of the DRB.

1.4.3 Schedule

The DRB will meet as required to satisfy the needs of the program.

1.5 Applicable Documents

The following was used as source documentation in the generation of this plan which has utilized license toward meeting the specific goals of a NASA Experiment.

(1)	NHB 8040.2	Apollo Configuration Management Manual
(2)	E1167	Apollo Drawing Standards
(3)	E1087	Documentation Handbook
(4)	NHB 5300.4 (1B)	Quality Program
(5)	NPC 200-3	Inspection System
(6)	NPC 250-1	Reliability Program

CHAPTER 2

CONFIGURATION CONTROL BOARD

2.1 Purpose

This procedure establishes the method for the release and revision of the technical data necessary to fulfill the design and configuration control responsibility assigned to CSDL on NASA experiments for Class I and II changes as related to these data. It establishes the method by which CSDL will control the design configuration as represented by the technical data released.

2.2 Scope

The procedures for release and revision of technical data require the

(1) Establishment of the CCB as an adjunct of the CMO for the formal processing of documents

(2) Identification and definition of documents which must be processed under this procedure

(3) Establishment of responsibilities in processing the release and revision of technical data

(4) Establishment of necessary forms and the distribution of data

2.3 Function

The CCB is the authorizing agency of CSDL for the initial release and subsequent revision of technical documentation for NASA experiments. This authority may be delegated to members as necessary to expedite the flow of technical documentation; however, the designated members must have approval authority commensurate with their responsibilities.

2.4 Procedure and Responsibilities

The formal and complete release of technical data requires the approval of the Authorizing Members of the CCB as specified in Section 2.5.1.

If any one approval is withheld, an agreement must be reached on the further action or disposition of the document, and responsibility for completing the action shall be assigned by the CCB Chairman.

The CCB functions on the assumption that complete coordination and understanding has been attained prior to presentation of the document for formal release. The formal meeting of the CCB presents the opportunity for the Authorizing Members to query in detail the other organizations involved as necessary before approval of the document.

The technical documents released by the CCB constitutes the authenticated sources of design data to be used in the manufacturing of the Experiment hardware.

The names of the Authorizing Members and their alternates designated by each organization shall be formally submitted to the chairman of the CCB for inclusion in the administrative record of the CCB.

2.5 CCB Membership

CCB membership is comprised of authorizing and participating members.

Authorizing members are the NASA representative and the CCB Chairman.

Participating members shall be as follows.

- Project Manager (or designate) (Chairman)
- Design group leader
- DRB, systems integration engineer, or other representation as required
- Document controller
- Recorder
- Contractor Support or observer personnel as required

The relationship of the CCB to the CMO is shown in the organization chart of Figure 1.

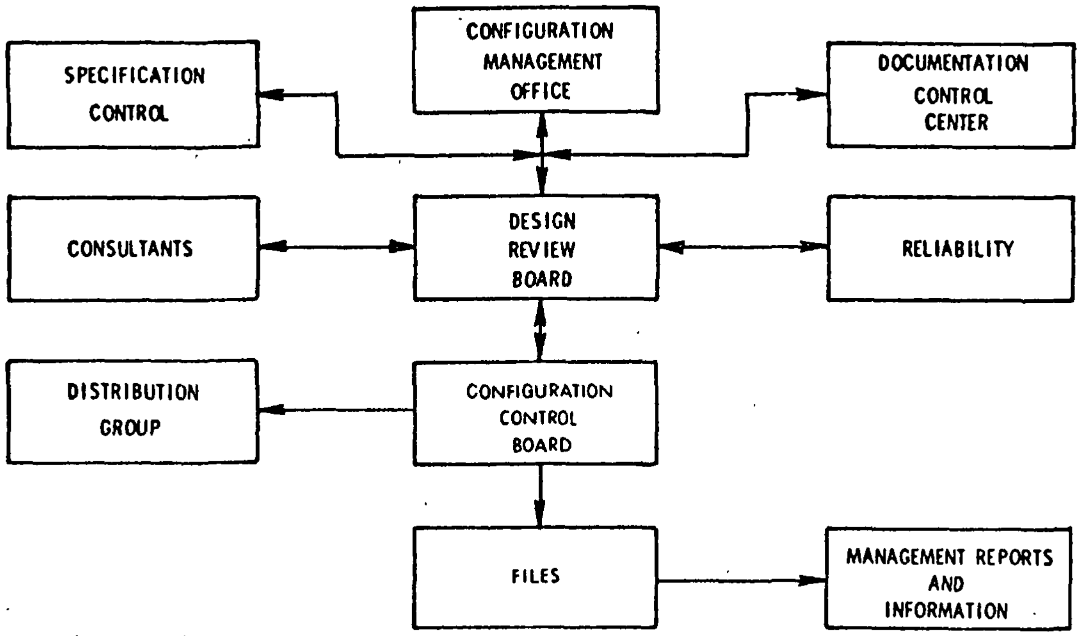

Figure 1 Configuration Control Organization Chart

2.5.1 CSDL Configuration Change Control Board Approval

The CSDL Configuration Change Control Board Approval indicates that the following CCB requirements have been fulfilled.

(1) Proper CSDL coordination and design approval

(2) Adequacy of information provided to fulfill requirements of the documentation control system

(3) Design approval of planned effectivity for configuration control

In addition a CSDL Authorizing Member shall

(4) Be chairman of the CCB

(5) Establish time and place of meetings

(6) Designate work load requirements

(7) Notify the required Participating Members

(8) Provide the support services (recorder and document controller)

2.5.2 NASA Approval

NASA Approval indicates the NASA Authorizing Member gives final approval to Class I and II changes to signify the Government's acceptance of the technical data and the possible program impact on cost, schedule and effectivity.

2.5.2.1 Participating Members

The Participating Members are in direct support of the Authorizing Members.

2.5.2.2 NASA

The NASA Participating Member shall act as requested by the Authorizing Member to support the Authorizing Member or to observe proceedings.

2.5.2.3 Manufacturing Contractor Approval (If Applicable)

The Manufacturing Contractor approval indicates that the contractor is:

(1) Accepting the technical data as binding within the cost, schedule, and effectivity designated. If the impact cannot be fully recognized, modifying conditions may be made on the ECR form,

(2) Presenting to the CCB any problems his organization forsees in carrying out the design intent, effectivity or any other consideration being imposed,

(3) Accepting the documentation requirements for correctness and format.

2.5.2.4 CSDL

The Participating Member for CSDL shall be the cognizant design group leader, system integration engineer, and/or other personnel required to present documents and supply additional information to the CCB.

2.5.2.5 Document Controller

The Document Controller is a required Participating Member to support the CCB Chairman in:

(1) Processing the approved CCB actions and documents into the documentation control system,

(2) Coordinating the CSDL support function of reproducing and distributing documents,

(3) Checking documents for completeness and accuracy of managerial information.

2.5.2.6 Recorder

The Recorder is a required Participating Member and provides services assigned by CSDL under the direction of the Document Controller. His activities will include, but not be limited to the following:

(1) Preparing for the CCB meeting and coordinating the schedule by ascertaining the number and types of releases and communicating with CCB members,

(2) Assisting the Document Controller,

(3) Maintaining a complete log of all items brought before CCB and the actions resulting,

(4) Assigning ECR numbers to completed CCB actions,

(5) Maintaining and publishing a record of CCB actions after each meeting, indicating ECR actions completed and reasons for rejection or delays of any unfinished ECR action,

(6) Providing typing and other clerical services at CCB as required,

(7) Distribution of released documents.

2.6 CCB Document Flow

Figure 2 shows the general flow of documents to and through the CCB, for all changes.

2.7 Identification of Data Subject to Change or Release Procedures

2.7.1 Purpose

The purpose of this section is (1) to identify the documents which are subject to the CCB Procedure, (2) to define the release and revision classifications, and (3) to identify the requirements unique to each classification.

2.7.2 Documents

The following, and changes thereto, must be approved by the CCB to become authorized documents for use in the production, testing, and acceptance of the NASA Experiments and/or any related equipment.

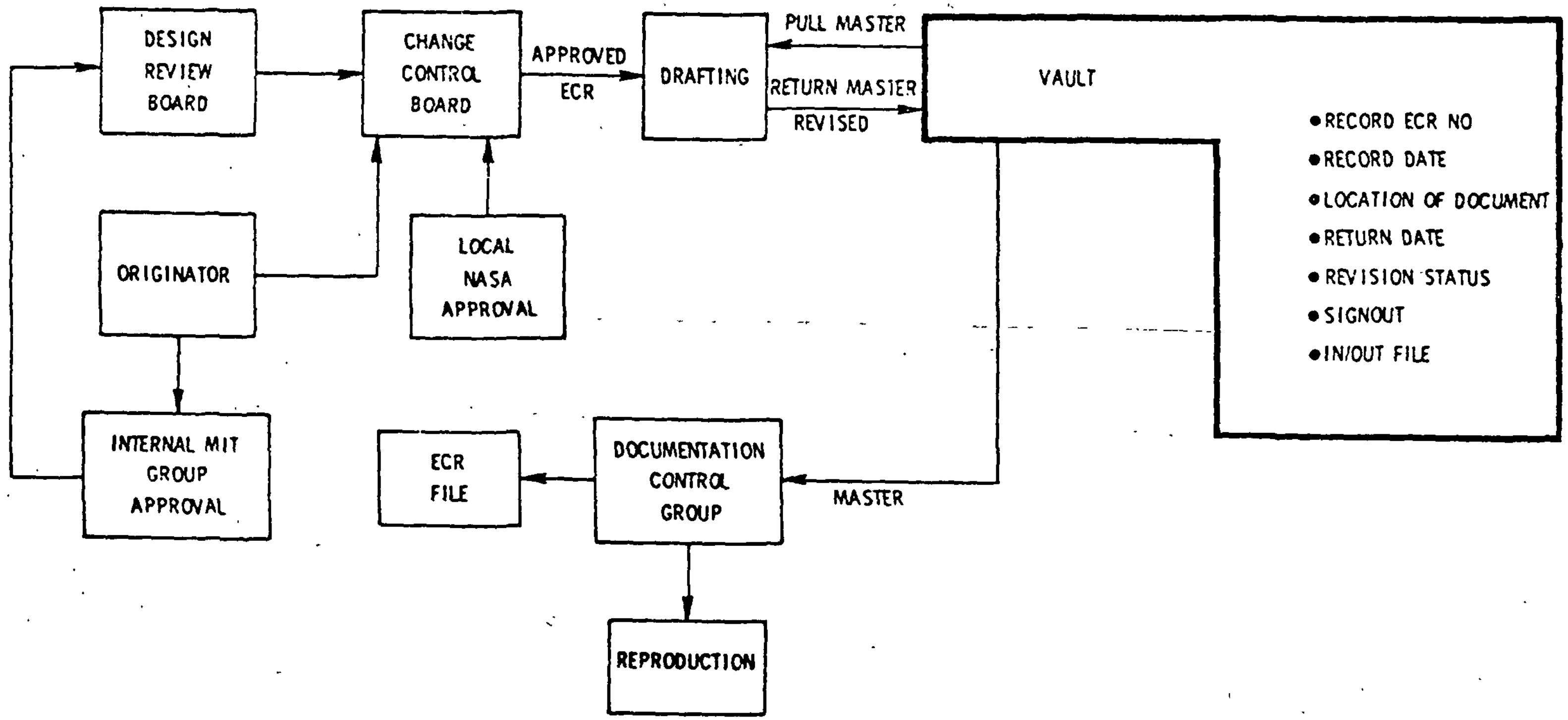

Figure 2 Basic Documentation Flow Control Chart

(1) All drawings, schematics, assemblies, parts lists, layout, packaging, and the like

(2) Procurement Specifications

(3) Specification Control Drawings (SCD's)

(4) Assembly Test Specification/ Procedures (ATS/ P)

(5) Process and Material Specifications

(6) Interface Control Documents (ICD's)

(7) Waivers/ Deviations

(8) Manuals

(9) Approved Suppliers List

(10) Computer Programs

This list does not preclude the addition of other documents for which a review cycle and document control may be desirable or mandatory.

2.7.3 Identification of Document Release Classifications A and B

Documents referred to herein are grouped into two classifications: Class A and Class B.

2.7.3.1 Class A Release

Class A documents are those which the project or design engineer designates as representing the design configuration to be used for operational hardware and supporting equipment. All documents that do not carry a Class B designation are to be considered Class A documentation. Changes to Class A documents must be rigidly controlled since such changes may affect interfaces, procurement specifications, tooling, and the like. Incomplete initial releases shall be subject to management approval prior to CCB action, and shall be approved only in exceptional cases. The DRB shall review and approve all initial Class A releases and Class I changes prior to CCB action. Class A documents are signed and authenticated releases.

2.7.3.2 Class B Release

Class B documents are essentially drawings and supporting documentation generated during the research and development stages of the program. They shall meet normal document standards and shall contain a Class B marking. Depending upon the phase of development, they may only partially fulfill the complete requirements of the document content.

Class B documents are representative of the current status of design development and are released in advance of completed design, prior to approval, in order to permit breadboarding and evaluation and to initiate planning and advance procurement in areas that are critical from a schedule standpoint.

It is normally expected that there may be numerous revisions to Class B documents, particularly drawings, before completion of design and Class A release. However, in order to meet schedules, Class B documents must be released at the earliest possible date. Limited advance procurement and/or fabrication of parts and assemblies built to Class B documents can be authorized whenever it is considered essential to maintain schedules. Acceptance testing and assembly of items procured, fabricated, or assembled for manned vehicles from this advance procurement based on Class B documentation shall meet the requirements of the resultant Class A releases. Drawings and documents issued as Class B releases for the purpose of breadboarding or evaluation of proposed design are continuously reviewed and should be upgraded to Class A releases as soon as possible.

The DRB shall review and approve all initial Class B releases and Class I changes prior to CCB action.

A Class B document can be upgraded to a Class A document when appropriate by approval of the DRB, removal of the Class B marking, and upon release by the CCB.

2.7.4 Revisions to Class A and Class B Documents

Since Class A and Class B documents represent two distinct phases of documentation, revisions to each class of document must of necessity be accomplished in such a manner as to support and implement the basic intent of the two classes of release. No changes to Class A documents can be made prior to CCB approval.

Changes to Class B documents are handled in the same way as changes to Class A documents, but special procedures may be devised by the CMO to handle special situations concerning Class B revisions.

In addition to the two classes of document release, revision to either class of document shall be divided into two broad categories, Class I and Class II, as defined below.

2.7.4.1 Class I Change (Reference NHB 8040.2)

An engineering change shall be classified Class I when one or more of the factors listed below (subparagraphs (a) or (b) or any factor(s) listed under (c), (d) or (e)) is affected:

(a) The functional or allocated configuration identification.

(b) The product configuration identification as contractually specified (or as applied to Government activities), excluding referenced drawings.

(c) Technical requirements below contained in the product configuration identification, including referenced drawings, as contractually specified (or as applied to Government activities).

- (1) Performance outside stated tolerance.
- (2) Reliability, maintainability or survivability outside stated tolerance.
- (3) Weight, balance, moment of inertia.
- (4) Interface characteristics.

(d) Non-technical contractual provisions.

- (1) Fee
- (2) Incentives
- (3) Cost
- (4) Schedules
- (5) Guarantees or deliveries

(e) Other factors

- (1) Government furnished equipment (GFE)
- (2) Safety
- (3) Electromagnetic characteristics
- (4) Operational, test or maintenance computer programs
- (5) Compatibility with support equipment, trainers or training devices/equipment.
- (6) Configuration to the extent that retrofit action would be taken.
- (7) Delivered operation and maintenance manuals for which adequate change/revision funding is not on existing contracts.
- (8) Pre-set adjustments or schedules affecting operating limits or performance to such extent as to require assignment of a new identification number.
- (9) Interchangeability, substitutability or replaceability, as applied to CI's, and to all subassemblies and parts or reparable CI's, excluding the pieces and parts of non-repairable subassemblies.
- (10) Sources of CI's or repairable items at any level defined by source control drawings.

Class I changes must be approved by the DRB prior to the CCB. The effectivity for a Class I change must be specified prior to the review by CSDL DRB. Any change made to the effectivity at the CCB will require re-approval of the DRB. The effectivity stated at the time of CCB approval shall be mandatory.

All proposed Class I changes shall be prepared as complete package changes. The changes must be defined in all areas of the drawing structure through the highest assembly affected, including Process Specification.

2.7.4.2 <u>ClassII Change (Reference NHB 8040.2)</u>

Any engineering change not falling within Class I as defined above shall be designated as a Class II change. Generally Class II changes are those changes which are desirable but not technically necessary from a system function standpoint. Changes required to comply with documentation format specifications would be in this class. A Class II change cannot change form, fit, function or reliability so as to affect interchangeability and will not result in the scrapping of any previously manufactured item. No effectivity is specified and the change is incorporated on the basis of no cost and no schedule impact.

The Inactivation or Obsoleting of documents shall be considered a Class II change. Inactivation and Obsoleting of documents are defined as follows.

(1) Inactivated : Inactivation of a document shall prevent further use of a document which has been released through the CCB and used to build, procure, test, or otherwise support hardware. The fact that the document has been "used" requires the designation of being inactivated and not obsoleted.

(2) Obsoleted : Obsoletion of a document shall prevent the use of a document which has been previously released through the CCB but never actually used to build, procure, test, or support hardware. Documents shall not be made Obsolete if any hardware has been built to the document.

When an ECR is prepared to incorporate a Class I change in a document, Class II changes are sometimes incorporated on the same ECR. Class II changes released in this manner automatically become Class I changes and are subject to all the requirements imposed for a Class I change, including the DRB review and approval prior to the CCB. Care must therefore be exercised that true Class II changes processed by this method do not produce a cost or schedule impact or result in nonessential changes to hardware.

If any change on the ECR is considered by the CCB to be Class I or if any doubt should arise concerning the Class II designation for a change, the entire ECR shall be submitted to the CSDL DRB for evaluation and approval. Normally, Class II changes shall not require CSDL DRB approval.

2.7.4.3 Determination of Revision Class

It is the originator's responsibility to initiate the change as Class I or Class II. Final determination of the class of change rests with the CSDL DRB and the CCB. When designating any change, the effects on interface activities including logistics, training, operation, reliability, and the like must be considered. Any change in the revision class effected at CCB shall require approval by the DRB.

2.7.5 Exceptions

Some documents are processed through CCB for record purposes only and to insure distribution throughout the system. Documents falling into this category are Interface Control Documents (ICDs). When documents of this type are submitted to CCB, the ECR should be boldly marked in the "Description of Changes" column "For Information Only," thus indicating that the signatures of the Contractor and NASA are not required.

2.8 Engineering Change or Release Documents

2.8.1 Introduction

The purpose of this section is to relate the ECR form to the procedures required for the release, revision and recording of technical data.

The required ECR form provides the means of processing data and a record of approved technical data.

2.8.2 Engineering Change or Release Form

The ECR form is the sign-off form for the CCB. It is serialized and recorded when approved as part of the Board's record and provides the only authority for the release or revision of NASA Experiment Systems technical data.

All the documents listed in Section 2.7 of this procedure require processing by ECR's for approval. The person who prepares the ECR form is responsible for assuring that there is a mutual understanding of the reason for the change and the effect of the change by the responsible engineering personnel at the Charles Stark Draper Laboratory, the Contractor's facility and the Government Agency. If documents are applicable to other systems, the changes must be coordinated through the associated groups.

2.8.2.1 ECR Form Rules

An initial release is defined as the procedure followed the first time an identification number is assigned to a document, part or assembly and the document is processed through the CCB. Subsequent revisions to the document which do not affect interchangeability are called "revisions" and are indicated by using the same identification number with appropriate change made to the revision letter. If a document has already been released and must be revised in such a manner as to cause a noninterchangeability of parts, a new identification number or a new dash number is assigned. If a new identification number (seven digits) is assigned to a replacing part, the new drawing shall be released through the CCB as an initial release.

If a new dash number is assigned to a replacing part, the action on that drawing is a revision through the CCB.

The action of replacement with a noninterchangeable part is evidenced on the next higher assembly where a new dash number must also be added to show noninterchangeability at this level, and progressively up to the level where interchangeability is re-established. To alert those who are concerned with effectivity and spares provisioning, the ECR may emphasize by note that the revision adding a new dash numbered configuration creates a noninterchangeable replacement.

The following rules apply for ECR's:

(1) Each ECR may include more than one document for initial release; however, when changes affect more than one drawing, a separate ECR shall be prepared for each revised drawing except in the following cases:

(a) All drawings to be made obsolete or inactive may be listed on one ECR Form.

(b) On package changes for which the effectivity and overall reason for the change are identical for several different drawings, even though the specific changes listed for each drawing may differ, a single ECR may be used for processing the entire release at CCB. The changes to each drawing itemized on the ECR must be completely described. The revision letter changes to each drawing shall be tabulated in the "Description of Changes" block.

(2) Each ECR for a revision must carry a complete description of the proposed change (i. e., FROM:, TO:) so that it is possible to effect the revision without further information. The change shall be fully described on the ECR and a marked-up reproducible shall accompany the ECR except when, in the judgment of the originator, the ECR is prepared in sufficient detail and clarity as not to be subject to misinterpretation, in which case the marked-up reproducible may be omitted.

(3) When "non-interchangeable replacements" are being prepared, the part number of the replaced part should be referenced.

(4) If a "reissue" of an ECR is used to correct errors which were present on it when it was originally issued, the original ECR is brought to CCB, where it is marked and initialed by those concerned to indicate the correction which is made. The document itself is not affected because the error exists only on the ECR. If the CCB review reveals a possible Class I change resulting from the correction (e.g., "effectivity"), the ECR shall be boldly marked at the top "REISSUE" and the minutes of the CCB Meeting shall record the action. (See Section 2.8.4).

(5) All ECR's are consecutively numbered by the CCB upon approval. The configuration control data contained in the approved ECR is recorded and released for distribution and documentation.

(6) All ECR's are to be typed.

2.8.2.2 Assignment of Effectivity

The following rules apply for assigning effectivity on ECR's.

(1) Effectivities associated with equipment shall be assigned in accordance with the sequence of system or subsystem (as applicable) end-item serial numbers. If "cut-in" only is indicated on the ECR, the effectivity applies to the serial number entered and to all subsequent hardware.

(2) The "cut-out" effectivity must be supplied whenever it is necessary to limit procurement or usage to an amount less than the total contract buy. The omission of a "cut-out" will be interpreted as indicated in paragraph (1) above.

(3) To change the effectivity specified for a previous revision without a documentation change will be handled by reissuing the latest applicable ECR.

(4) Contract End Item Serial numbers will be assigned in accordance with NHB 8040.2.

2.8.2.2.1 Requirements for Effectivity

The following ground rules identify the minimum requirements for the assignment of effectivity and do not preclude conformance with additional requirements, not stated herein, which are also contractually imposed.

(1) Effectivity shall be specified for all Class I changes. Revisions to "mechanization drawings" shall be exempted from this requirement.

(2) If the effectivity of a Class I change affects spares, it shall be indicated on the ECR in such a way as to clarify the required changes to spares.

(3) If a change results in a non-interchangeable item, the identification number of the non-interchangeable item and of its next higher assembly, and of all progressively higher assemblies shall be changed up to but not including the level where interchangeability is re-established. The effectivity

changes shall be assigned as required to identify the new configuration or application. These changes shall be processed as a package change.

(4) The total applicability of a document when considering a particular change to its use shall include all related documents. All affected documents shall be processed as a package change.

(5) Effectivity of a change to a dash-number type of document applied only to the dash-number specified on the ECR, and does not affect the effectivity of the other dash-number configurations on the drawings. When more than one dash-number is affected by the revision, the effectivity for each of the affected dash-numbers shall be indicated.

(6) No effectivity shall be assigned to Class II changes.

(7) No effectivity shall be assigned when a new item is released. Effectivity for such items is determined by reference to the assembly drawings which call out the new items.

2.8.2.3 Instructions for Preparation of ECR

Instructions for preparing ECR's are detailed below (see Figure 3 for the sample ECR form). All items on the form will be completed. "NA" (not applicable) or NONE will be used if necessary.

Item 1 ECR No.
A five digit ECR number will be assigned by CCB for each approved ECR.

Item 2 ORIGINATOR CONTROL No.
This block is used for an in-house control identification number when needed prior to release by CCB.

Item 3 PROGRAM
Title or letter abbreviation of NASA Experiment or project. Enter the Customer contract number and the document number or CEI number.

Item 4 DOCUMENT No.
Enter the identification number of the document being processed by the ECR. (See Item 28 for multiple document numbers.)

CHARLES STARK DRAPER LABORATORY

ENGINEERING CHANGE OR RELEASE

ORIGINATOR CONTROL NO 2 SHEET 1 of ____

PROGRAM 3	CONTRACT NO 3
CEI/CES NO 3	ECR NO 1

DOCUMENT NO	REVISION FROM	REVISION TO	DOCUMENT TITLE	TYPE DOCUMENT
4	5	5	6	7

ORIGINATOR 8		SYSTEM/SUBSYSTEM 9	EFFECTIVITY 10
ORGANIZATION 8	DATE 8		

REASON(S) FOR CHANGE/RELEASE

11

DESCRIPTION OF CHANGE(S)/RELEASE(S)

12

CHANGE CLASS	NEXT HIGHER ASSY	MASTER DOCUMENT LOCATION	DOCUMENT NO. REPLACED
13	14	☐ CSDL 15 ☐ ____ ☐ ____ ☐ ____	16

AFFECTED DOCUMENTS	RELATED ECR NOS	AFFECTED INTERFACES
17	18	19

AFFECTED CONTRACTS	REMARKS
20	21

CSDL ENGINEERING APPROVAL 22 DATE	MFG. CONTRACTOR APPROVAL 26 DATE
R&QA APPROVAL 23	NASA APPROVAL 27 DATE
CSDL DESIGN REVIEW APPROVAL 24 DATE	
CSDL CHANGE CONTROL BOARD APPROVAL 25 DATE	

1P22924-1

ECR NO 1

Figure 3

SHEET ___ OF ___

CHARLES STARK DRAPER
LABORATORY

ENGINEERING CHANGE OR RELEASE

PROGRAM	CONTRACT NO.
3	3
CEI NO.	**ECR NO.**
3	1

DOCUMENT NO.	REVISION FROM	REVISION TO	DOCUMENT TITLE	TYPE DOCUMENT
4	5	5	6	7

DESCRIPTION OF CHANGE(S)/RELEASE(S) (CONT'D)

12

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ECR NO. 1

Figure 3 cont.

Item 5 REVISION

Enter the current revision letter under "FROM" and the new revision letter under "TO." In the case of the initial release of a document a "-" shall be entered in the "TO" column. If the document is being initially released with a revision status, "-A", "-B", etc., shall be entered in the "TO" column. (See Item 28 for revisions to multiple documents.)

Item 6 DOCUMENT TITLE

Enter the complete title of the document. (See Item 28 for multiple document titles.)

Item 7 TYPE DOCUMENT

Indicate the type of document being released or changed by the ECR. Example: Dwg., SCD, PS, etc.

Item 8 ORIGINATOR

Indicate the name of the individual preparing the ECR, the organization he represents and the date of preparation.

Item 9 SYSTEM/SUBSYSTEM

Enter the name of the assembly or subassembly on which the item appearing under "DOCUMENT TITLE" will be used. For example, if the item listed under "DOCUMENT TITLE" were "Directional Gyro," the subsystem would be the "Gyro Assembly."

Item 10 EFFECTIVITY

Enter the serial number of the first and last contract end item that will have the change incorporated. If only one serial number is specified, then the effectivity applies to that serial number and all subsequent serial numbers. The last serial number must be supplied whenever it is necessary to limit procurement to an amount less than total contract buy. When a new item is released, this block will be left blank. The effectivity of the new item will be determined by reference to the assembly drawing which calls for the new item. Effectivity must be specified for all Class I changes. Some examples: "1 - 6"

Item 10 (Cont) indicates that this change will be effective for serial numbers 1 through 6 inclusive. "3" indicates that the change is effective for serial number 3 and all subsequent serial numbers. "4 only" indicates that this change is effective for serial number 4 only.

Item 11 REASON(s) FOR CHANGE/RELEASE

Enter the precise reason for the change. This reason must be complete enough to permit the evaluation of the proposed change. *If the ECR is releasing a new item,* "Initial Release" shall be entered here.

Item 12 DESCRIPTION OF CHANGE(s)/RELEASE(s)

Supply a complete description of the changes indicating the present condition (FROM) and the specific way the document is to be revised (TO). Supplementary reproducible sheets 8 - 1/2 by 11 inches in size may be included to amplify the description when the change involves extensive modifications. In certain cases, a reduced-size, marked, reproducible copy of the drawing is permitted to serve as a second page of the ECR. The ECR number is required on the reproducible. The description of the desired change must be complete enough to allow incorporation without any further clarification or interpretation. (See Item 28 for multiple documents.)

Item 13 CHANGE CLASS

Indicate the appropriate change classification,i.e.: Class I or Class II.

Item 14 NEXT HIGHER ASSEMBLY

Indicate the next higher assembly for the document being processed by the ECR. (See Item 28 for multiple documents.)

Item 15 MASTER DOCUMENT LOCATION

Indicate the location of the master document and the activity responsible for incorporating the document revision completely as outlined on the ECR.

Item 16 DOCUMENT NUMBER REPLACED

If the ECR is releasing or revising a document that falls into the category of establishing a new non-interchangeable replacement part, the part number of the old part shall be indicated.

Item 17 AFFECTED DOCUMENTS

Indicate all other drawings, specifications, or documents that are affected as a result of this change. If the revision resulted in a change to these documents, indicate the revision at which this change took place. If the revision is still under preparation and the revision letter cannot be forecast, indicate this by the letters "UR" (under revision). When possible, associated documents which must be revised as a result of the described revision shall be submitted simultaneously with the original change; the complete revision shall then be submitted as a "Package".

Item 18 RELATED ECR NUMBERS

The ECR number for those documents listed in Item 17 that are submitted as a "Package" will be assigned by CCB.

Item 19 AFFECTED INTERFACES

If a physical or electrical change affects the interface with another subsystem, indicate the document title and number of the affected subsystem. Also enter the title and number of the Interface Control Document or Specification if affected.

Item 20 AFFECTED CONTRACTS

Indicate the MIT Sub-Contract or Industrial Contract number affected either directly or through an interface, by issuance of the ECR.

Item 21 REMARKS

This should be accomplished at the time of CCB approval.

Item 22 ENGINEERING APPROVAL AND DATE

The signature of the responsible design engineer and the date must be entered. This must be accomplished at or prior to submission to the DRB and CCB.

Item 23 QA/RELIABILITY APPROVAL AND DATE

The signature of the responsible QA/Reliability engineer and the date (when specified).

Item 24 DESIGN REVIEW APPROVAL AND DATE

The signature of the chairman of the DRB, or his designated representative and the date will be entered to indicate design approval. This must be accomplished prior to submission to CCB.

Item 25 CONFIGURATION CONTROL BOARD APPROVAL AND DATE

The signature of the Configuration Control Board authorizing member and date are affixed during the CCB meetings.

Item 26 MANUFACTURING CONTRACTOR APPROVAL AND DATE (where applicable)

The signature(s) of the appropriate contractor(s), his affiliation and the date when applicable. This should be accomplished at the time of CCB approval.

Item 27 NASA APPROVAL

Authorization of contracting agency or designate, as required.

Item 28 MULTIPLE CHANGES/RELEASES

One ECR form may be used to process multiple changes/releases whenever the information contained in Items 3, 7, 8, 9, 10, 11 and 13 pertain to all of the changes/releases. This may be accomplished by listing the following information in Item 12.

Item	Document No.	Revision From	Revision To	Document Title	Next Higher Assy

When the ECR is processing multiple changes the following additional information will be furnished following the above listing.

Item 1 Document No.

(Description of change)

Item 2 Document No.

(Description of change)

etc.

2.8.3 ECR Procedures

ECR forms and the documents being processed for approval may be originated by CSDL or the Contractor responsible for the manufacture of the equipment in question.

2.8.3.1 Initial Release of Documents Maintained by CSDL

Class A and Class B documents shall be released by the following procedure.

2.8.3.1.1 CSDL Originator

The CSDL originator of the document shall provide blueline copies (or reproducible on request) to the Contractor and to the CSDL DRB members of each document to be released. These copies should be provided at the earliest possible date prior to submission to DRB and CCB. The ECR forms shall be prepared by the originator.

2.8.3.1.2 Contractor

The Contractor shall review the blueline copies of drawings prior to CCB action and prepare any pertinent comments relative to, but not limited to, production, design, interface, cost, effectivity, or schedule impact. He must be prepared to complete an Engineering Change Proposal (ECP) form, even though it may only be an ECP of record.

2.8.3.1.3 CSDL Design Group Leader

The design group leader shall

(1) Process copies of the proposed Class A documents through DRB

(2) Coordinate with the CSDL Reliability Group for SCDs, procurement specifications, assembly test specifications and procedures, and process and material specifications.

(3) Consolidate DRB, Contractor and Reliability Group recommendations and submit documents and ECR's to CCB after DRB approval.

2.8.3.2 Initial Release of Documents Maintained by the Contractor (When applicable)

Class A and Class B documents shall be released by the following procedure.

2.8.3.2.1 Contractor

When the Contractor is the originator, he shall prepare the proposed documents to be released by CSDL in accordance with CSDL procedure. Blueline copies of each document to be released shall be provided to the cognizant CSDL engineer and to the DRB members. These bluelines should be provided at the earliest possible time. The Contractor shall prepare and submit the ECR and the document master to the CSDL design group leader and prepare ECP forms if necessary.

2.8.3.2.2 CSDL Design Group Leader

The CSDL design group leader shall

(1) Review the drawing prior to submission to DRB and and CCB and prepare any pertinent comments relative to, but not limited to, production, design, interface and effectivity

(2) Process the proposed documents through DRB for release

(3) Consolidate DRB CSDL Engineering and Reliability Group recommendations, and submit document masters and the ECR's to CCB.

2.8.3.3 Revisions to Documents Maintained by CSDL

Revisions to documents maintained by CSDL shall be accomplished in the manner described below.

2.8.3.3.1 Originator

Prior to DRB and CCB meetings, the CSDL originator of the proposed revision shall supply copies of each revision, in order to provide advance information, to the following.

(1) One reproducible copy to the Contractor for planning purposes and cost estimation.

(2) One blueline copy for reliability review when applicable. This copy then goes to DRB for review.

2.8.3.3.2 Contractor

The Contractor shall review a copy of the revision prior to CCB action and prepare any pertinent comments relative to, but not limited to, production, design, interface, cost, effectivity, or schedule impact and prepare an ECP if necessary.

2.8.3.3.3 CSDL Design Group Leader

The design group leader shall

(1) Process the proposed document revision through DRB if necessary.

(2) Coordinate with the Reliability Group for PS's, SCD's and ATS/P.

(3) Consolidate DRB, Contractor and Reliability Group comments.

(4) Group recommendations and submit documents with their ECR's to CCB.

After the CCB approval, the drafting department shall

(1) Incorporate the document revision completely as outlined on the signed ECR

(2) Add the CSDL ECR number to the document, raise the document revision to the next sequential revision (must agree with the ECR), and deliver the revised document to the chairman of the CCB within one week after the signed ECR is received from CCB.

(3) Deliver the signed documents to the Document Controller for distribution.

2.8.3.4 Revisions to Documents Maintained by the Contractor

Prior to DRB and CCB meetings, the Contractor who originates the proposed revision shall provide copies of each drawing in order to provide advance information to the following.

(1) One reproducible copy or marked-up reproducible to the cognizant engineer at CSDL for evaluation of the proposed revision.

(2) One copy for Reliability Group review when applicable. This copy then goes for system interface review at DRB.

(3) If the revision originates at CSDL, the procedure is similar to that described in Section 2.8.3.3 except that the Contractor will finally incorporate the change as specified in this section.

For actual submittal to CCB, the Contractor shall prepare the proposed revision package and submit it to the CSDL cognizant engineering group through the CSDL CMO. The package shall contain a reproducible or marked-up reproducible of all revised documents and a completed ECR form. He shall also prepare an ECP if necessary.

2.8.3.4.1 CSDL Design Group Leader

The CSDL design group leader shall

(1) Process the proposed documents through DRB if necessary

(2) Coordinate with the Reliability Group for PS's and SCD's.

(3) Consolidate DRB, cognizant engineer, and Reliability Group recommendations and submit documents with the associated ECR's to CCB.

2.8.3.4.2 Contractor, after CCB

Upon receipt of the approved ECR's, the Contractor shall perform the following.

(1) Incorporate all approved changes as specified by the signed-off ECR and supported by a marked-up drawing or specification when necessary.

(2) Add the CSDL ECR number to the document, raise the document revision to the next sequential letter (must agree with the ECR), and affix his initial. The initial indicates that the approved revision has been incorporated completely and accurately in the master document.

(3) Deliver a reproducible copy of the updated document to CSDL for distribution.

2.8.3.5 <u>Procedure to Make Documents Obsolete</u>

<u>An ECR shall be prepared to make documents obsolete only when a sufficient quantity has accumulated to make a worthwhile package.</u> The ECR shall be reviewed and approved by the DRB and CCB.

2.8.3.5.1 The revision letter on a document which is made obsolete shall not be changed to effect the obsolescence; however, the word "OBSOLETE" and the date of obsolescence shall be written above the title block on the master of the document. The document is submitted with the ECR to CCB.

Identification of the obsolete documents shall appear in the Document History Log (See Figure 4). No document distribution will be prepared to reflect obsolescence.

The identification number assigned to a document shall not be re-assigned after the document is made obsolete.

2.8.3.6 Procedure to Make a Document Inactive

A document shall be inactivated only if one of the following conditions exists.

(1) The document is being released by another document which shall be used for all former applications of the inactive document, or

(2) All hardware supported by the document has been retrofitted and subjected to the requirements of a new document, scrapped or otherwise removed from use.

2.8.3.6.1 When an ECR is processed to release a replacement document as described in Items (1) and (2) above, the document which is inactivated shall be identified on the same ECR as a separate action item.

Identification of inactive documents shall appear in the Document History Log.

The identification number assigned to a document shall not be reassigned after the document is made inactive.

2.8.4 ECR Corrective Actions

This procedure outlines the corrective action to be followed when the issued ECR and drawing are not in accordance with each other at the same revision letter.

The two situations and the applicable procedures are identified as follows.

(1) New ECR. If the ECR is correct but the drawing does not reflect the change shown on the ECR:

(a) Make out a new ECR.

(b) Cross-reference should be made to the old ECR by stating in the "Reason for Change" block that "above changes listed on ECR _____ were not incorporated on the drawing at Rev ____."

(c) List on the new ECR only those changes that were omitted on the drawing.

(2) Reissue ECR. If drawing is correct but the ECR is not correct:

(a) Mark up a copy of original ECR to correct the ECR errors for reissue of ECR.

(b) In the "Remarks" block give reason why ECR is being reissued. Mark "Reissue" into border of ECR. At least one day prior to the next scheduled CCB meeting a list of all the ECR numbers being reissued will be given to the CCB recording secretary. This will give the secretary ample time to have original ECR's available for the CCB meeting.

During the CCB meeting a marked-up copy of the ECR will be presented to the board by the design group representative. If approved, a CCB member will transfer this information to the original ECR with the reason for being reissued and the cognizant CSDL engineer will initial the change for processing through the CCB.

2.8.5 Documents

2.8.5.1 The Project Document History Log

The Project Document History Log is the official design release record for those documents which are issued to implement technical direction. (See Figure 4 Sample Format). It identifies all drawings, specifications and other documents released by the CCB for the production, procurement, assembly, inspection and use

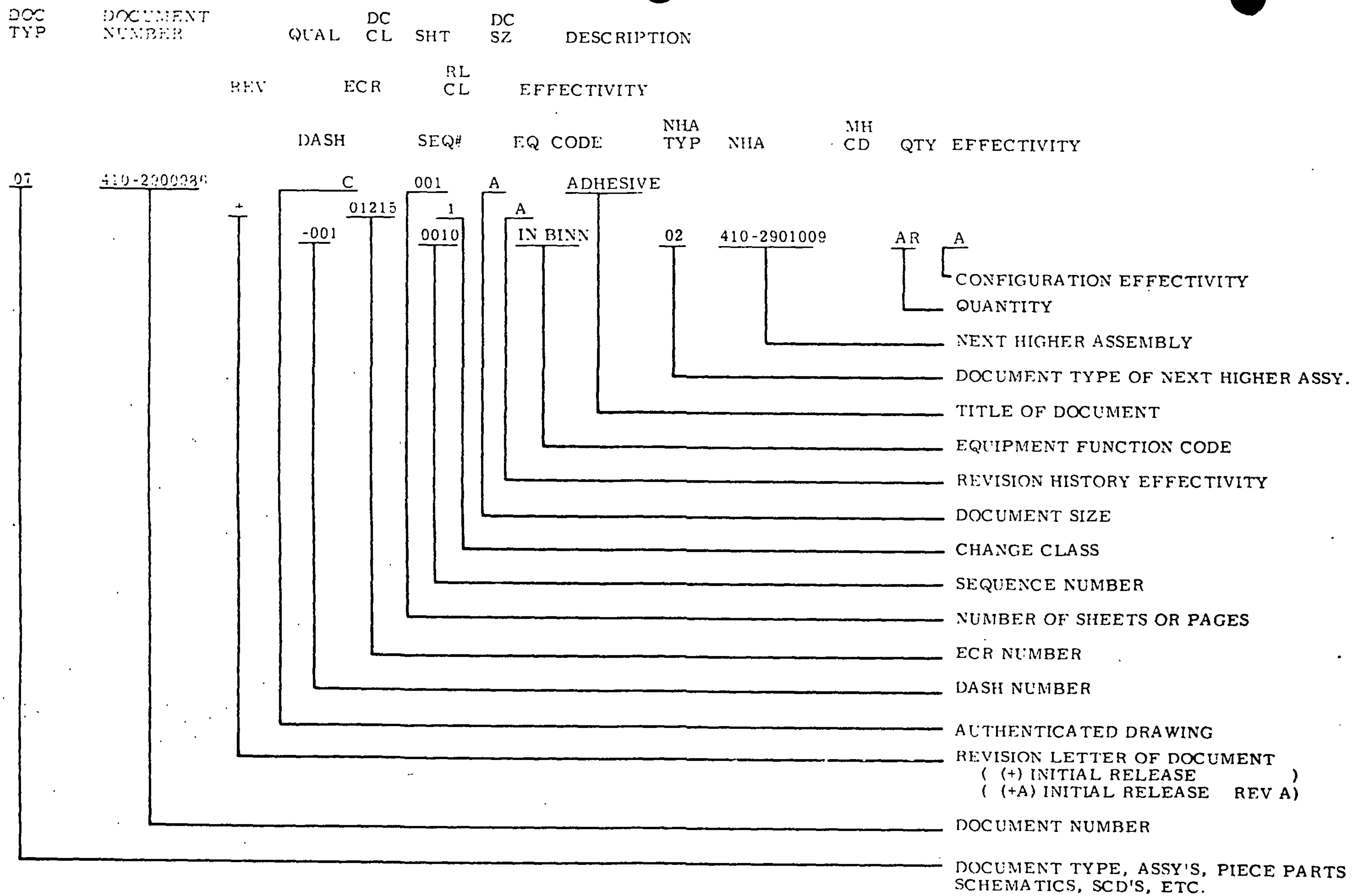

Figure 4 Document History Log.

of Project hardware, including test equipment.

2.8.5.2 End Item Configuration Family

The End Item Configuration Family Trees may be a pictorial representation of the hardware configuration for each end item. The level of preparation shall be down to the piece part level and also include all other associated documentation such as specifications, schematics, etc. (See Figures 5 and 6).

2.9 Special Instructions

2.9.1 Nonconformance Documentation

2.9.1.1 Material Review Board (MRB) Reports

The reports of MRB's are usually in the form of Variation Permits, requested by a Contractor and submitted for approval to CSDL. The CSDL CMO controls format and procedure.

2.9.1.2 Waivers

All waivers are identified to part number and serial or lot number of the part, assembly, or end item involved. No waiver may be written to cover more than one single system or subsystem. No "blanket waivers" are permitted. If more than one system incorporates the same nonconformance, separate waivers are required for each of the systems. No additional changes shall be made to the face of the waiver after it has been put in process. If substantiating technical data are considered necessary, attachments shall be made to the waiver. A sepia copy of the complete waiver shall be furnished to the CSDL Project Director, who will insure the listing of the waiver in the CSDL documentation control system.

2.9.1.2.1 Contractual Waivers

A Contractual Waiver is originated by the Contractor when a nonconformance exists that adversely affects the safety, reliability, performance, interchangeability, weight or any other basic objective of the contract.

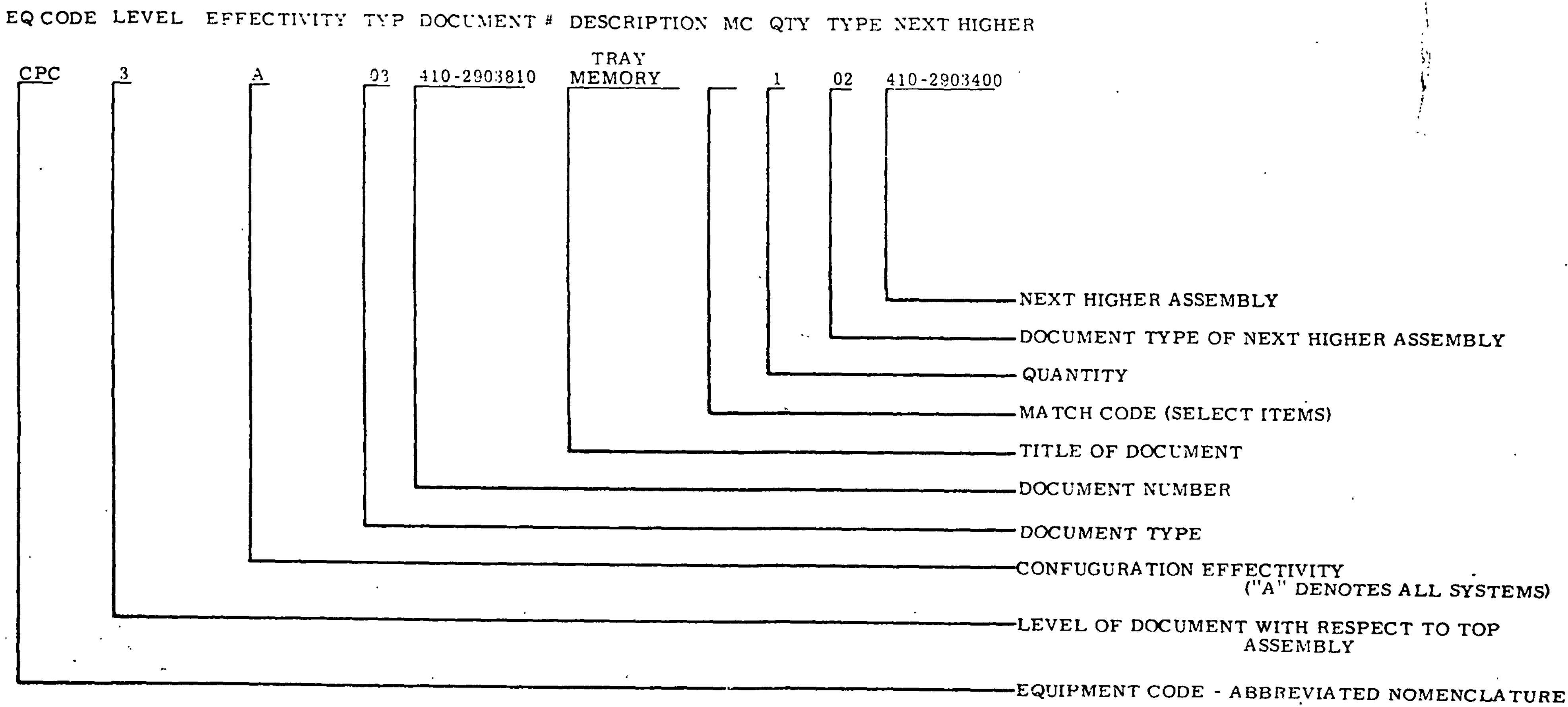

Figure 5 Configuration Family Tree

Figure 6 Glossary

CONFIGURATION FAMILY TREES

Equipment Code:	abbreviated title of the equipment
Level:	pertains to the level of a document with respect to the top assembly. Example: level 1 - top assembly level 2 - items called out on top assembly level 3 - documents called out on level 2 items level 4 - documents called out on level 3 items The computer will list all information on top drawing and parts list and then break each item down to its lowest level.
Effectivity:	where equipment "cuts-in" to the CEI serialization ("A" denotes all systems)
Type:	part number (Document number and dash number)
Part #:	part number (Document number and dash number)
Description:	title of document
M C:	match code (select items)
Qty:	quantity on next higher assembly
Type:	document type of next higher assembly
Next Higher:	next higher assembly (NHA) (used on)

Figure 6 (cont.) Glossary

DATA BANK DOC TYPE CODES

CODE	
01	ASSEMBLY
02	PARTS LIST
03	DETAIL OR PART
04	ELECTRICAL SCHEMATIC
05	INTERCONNECT DIAGRAM
06	RUNNING LIST
07	SOURCE CONTROL (SCD)
08	SPEC CONTROL (SCD)
09	INTERFACE CONTROL
10	DATA LIST
11	INDEX LIST
12	REVISION NOTICE
13	MIL SPECS (MIL-D-XXXX, MIL-Q-XXXX, MIL-M-XXXX)
14	FED SPECS (UU-P-XXXXX, CCC-C-XXX)
15	BU WEPS SPECS (JAN)
16	KIT CONTENTS LISTING
17	MIL STANDARDS (MIL-STD-XXX)
18	AN SPECS (AN, NAS, MS)
19	INDUST ASSOC STDS (ASTM)
20	MIT SPECS (S-SC-XXXX)
21	NASA SPECS (OD XXXXX)
22	PROCUREMENT SPECS (PS 410-290XXXX)
23	FACTORY ACCEPTANCE TEST
24	INSTALLATION PROCEDURE
25	CONTRACT END ITEM (CEI 410-290XXXX)

Coordination of the waiver is accomplished with CSDL through the CMO via telephone and/or datafax. CSDL concurrence or non-concurrence is to be accomplished within 48 hours. Format, routing, distribution and designation of authorizing signatures are a CSDL responsibility. This type of waiver requires CSDL signature approval (design cognizance and DRB).

2.9.1.2.2 Engineering Waiver

Engineering Waivers shall have no contractual implications; therefore cost and schedule impact are not a consideration. These waivers are initiated by CSDL or a Contractor.

This type of waiver is initiated when material or items are to be used "as is" and when they possess the following kinds of nonconformance.

(1) Functional nonconformances other than those defined in Section 2.9.1.2.1 provided that there is no adverse effect on the safety, performance, weight, interchangeability, durability, reliability, or system performance for customer acceptance of demonstrable parameters and the nonconformances do not have an unsatisfactory contract cost or schedule impact.

(2) When PS's, ATS/P's or drawing errors exist for which an ECR request has been initiated.

(3) Performance of the deliverable equipment is out-of-tolerance and the condition is defined to be caused by a test equipment inadequacy.

2.9.1.2.3 CSDL Waiver and Deviation Procedure

The purpose of this procedure is to define the responsibilities of CSDL personnel in the initiation, preparation and processing of waivers and deviations.

2.9.1.2.3.1 Waivers (See Figure 7)

A waiver is a written, approved authorization to enable the inspector to accept designated items which are found not to meet contract requirements during production or during inspection.

CHARLES STARK DRAPER LABORATORY

DEVIATION / WAIVER REQUEST

CATEGORY A ☐ B ☐ C ☐ D ☐

DATE ____________

SHEET ___ OF ___

PART NUMBER ____________ NOMENCLATURE ____________

NEXT ASSEMBLY ____________ FINAL ASSEMBLY ____________

SERIAL NUMBER ____________ QUANTITY INVOLVED ____________

VENDOR ____________ CONTRACT NUMBER ____________

PURCHASE ORDER NUMBER ____________ TYPE FP ☐ CPFF ☐ CPIF ☐

DETAILS OF NON-CONFORMITY:

REASONS FOR NON-CONFORMITY:

ACTION THAT MIGHT BE TAKEN TO CORRECT DEFECT IN EXISTING ITEM, IF ANY:

ACTION TAKEN TO PREVENT RECURRENCE OF NON-CONFORMITY:

EFFECT ON PRODUCTION SCHEDULE/COST IF REQUEST NOT APPROVED:

LIMITATIONS OF USAGE: YES ☐ NO ☐

APPROVALS

____________ RELIABILITY

____________ ORIGINATOR

____________ DESIGN ENGINEERING/DRB

____________ CMO

____________ CUSTOMER REPRESENTATIVE

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Figure 7

All waivers are identified to part number and serial or lot number of the part, assembly, or end item involved. No waiver shall be written to cover more than one single system or subsystem. No blanket waivers shall be permitted. If more than one system incorporates the same nonconformance, separate waivers are required for each of the systems. No additional changes shall be made to the waiver after it has been put in process. Whenever substantiating technical data is necessary, attachments shall be made to the waiver.

2.9.1.2.3.2 Deviations (See Figure 7)

A deviation is a written approved authoriziation, granted prior to the production, procurement or performance, of the affected item, allowing noncompliance with or variance from a contract requirement.

The second paragraph of Section 2.9.1.2.3.1 (Waivers) shall also apply to deviations.

2.9.1.2.3.3 Classification of Waivers and Deviations

In order to facilitate the delegation of authority to act on waiver and deviation requests, the following categories of requests are established.

(1) Category A includes requests which concern material, process or equipment characteristics which, if defective, do one or more of the following.

(a) Could or would result in hazardous or unsafe conditions for individuals during use, handling, stowage, shipment or maintenance of the product.

(b) Conflict, directly or indirectly, with Project Coordination Drawings or Systems specifications or otherwise affect coordination or compatibility with other equipment.

(c) Would result in failure or degradation of performance to the extent that the system fails to meet minimum performance.

(d) Would materially degrade the reliability of the system or subsystem.

(2) Category B includes requests, other than those in Category A, which concern material or equipment characteristics which, if defective, do one or more of the following.

(a) Would result in failure or degradation of performance, but not of such magnitude as to fail to meet System requirements.

(b) Affect interchangeability of replaceable components.

(c) Would measureably reduce the expected life of the affected equipment.

(3) Category C includes requests other than those in Category A or B, that could reduce, but not materially, the useability of the materials or equipment, or that could delay further processing or assembly.

(4) Category D includes requests other than those in Category A, B or C which in no way affect the useability of the item, or of other equipment with which it is used.

2.9.1.2.3.4 Procedure Definitions

For the purpose of this procedure the following definitions shall apply.

(1) Coordination

Coordination attributes of an equipment are those features that affect or are affected by the physical and functional mating (including weight) of the equipment with other parts or equipments in the system in which it is used.

(2) Life

Requirements that contribute to life design objectives are those features created to resist fatigue and deteriorating conditions of environment and wear in use and in storage. In general, pertinent life design characteristics are:

(a) Specific physical, electrical and chemical characteristics such as hardness, tensile strength, and related criteria.

(b) Protective coatings, plating and surface treatments and finishes.

(3) Interchangeability

The requirements that contribute to interchangeability are those pertaining to functional and physical characteristics that will assure proper mating of repair parts at point of service use without selective fitting.

(4) Function

Function characteristics are those that affect the operation and use of the item. They are generally those that define such things as mechanical or electrical output or chemical action, or other performance criteria.

(5) Safety

Safety characteristics are those features that reduce the hazard to personnel handling, using, or maintaining the equipment.

2.9.1.2.3.5 Preparation of the Nonconformance Authorization Format

Whenever a nonconformance exists which requires a deviation or waiver, the cognizant engineer shall inform his group leader of this condition. If it is obvious that this condition cannot be corrected by standard documentation changes (such as Engineering Change Request or Specification Change Notices) before "sell-off", *the engineer shall request a nonconformance form from the* documentation group. The documentation group shall decide if a waiver or deviation is applicable and shall assign a number to the form. The engineer shall then fill out the applicable sections and return the form to the documentation group which shall then complete the form and obtain necessary signatures.

A detailed instruction for preparation of the Nonconformance Authorization action is included below.

a. Firm Name and Address

b. Nonconformance Authorization

When it has been determined whether the nonconformance is a deviation or a waiver the nonapplicable term shall be crossed out.

c. Number

The documentation group shall assign consecutive numbers beginning with 001. There shall be separate numbers for waivers and for deviations.

d. Sheet of

Insert 1 in first blank and total number of sheets required in second blank.

e. Prepared By

Originating or cognizant Engineer shall sign his name.

f. Date

Insert date when number is assigned.

g. Contract No.

The number of the Prime Contract shall be entered.

h. Type of Contract

Enter type of contract.

i. Component/System Affected

Component nomenclature and system nomenclature shall be entered.

j. Serial No. Affected

Serial numbers of component and system shall be entered.

k. Impact

Documentation Schedule Cost Certification

Place a check mark in those areas which are affected. Define on an additional sheet(s) why and to what extent these areas are affected.

l. Category

Check the applicable category. See Section 2.9.1.2.3.3 for definition of categories. Define on additional sheet(s), the consequences of not correcting nonconformance.

m. Present Condition -- Provide a description of the existing condition.

Reasons for Existing Condition -- State the reason the nonconformance condition exists.

n. Recommended Corrective Action

Existing Units -- Provide a solution to correct the deficiency in the existing unit(s).

Future Units -- Provide a solution to correct the deficiency in future unit(s).

o. The remaining blocks are for approval signatures. The responsible personnel shall sign their name and the date of signature.

2.9.2 Engineering Change Proposal (ECP)

NHB 8040.2 is the governing document for the ECP procedure. Those changes which require ECP action shall be prepared in accordance with this document. Whenever an ECP involves a change to a specification, a specification Change Notice shall be prepared and attached to the ECP.

2.9.2.1 ECP Recommendations

Recommendation for ECP action may be originated by NASA, CSDL or any sub-contractor. In each case, CSDL will initiate the ECP and submit it as stated above.

2.9.2.2 ECP Preparation

The MIL-STD-480 ECP procedure shall be used as a guide in the preparation and submission of all ECP's. The ECP coordinator shall assist in the preparation of ECP's, and shall establish coordination meetings as required.

CHAPTER 3

CHANGE CONTROL AFTER DELIVERY OF EQUIPMENT

3.1 Retrofit Kit Release, Revision, and Marking

When it is proposed that a retrofit modification is required or desired in delivered equipment, action is necessary to insure proper documentation of the change. This procedure identifies the necessary documentation and approvals for retrofit actions. Every retrofit action will carry an ECP as defined by NASA procedures (ref., NHB 8040.2) to recognize any required work requirements for contract purposes.

3.1.1 Retrofit Kit Content

The retrofit kit will contain all the necessary parts, unique tools, and necessary engineering drawings required to accomplish the modification. In addition, each kit will contain a Retrofit Instruction Bulletin (RIB) when the retrofit is to be accomplished at field locations.

3.1.1.1 Retrofit Instruction Bulletin (RIB)

The Retrofit Instruction Bulletin shall be prepared by the Contractor for modification of hardware for which he has cognizance. The RIB shall contain all required instructions (special disassembly or assembly techniques, and the like) for installation of the kit. It shall also contain descriptions of the required retesting to insure that the modified equipment adheres to all specification requirements. The retesting requirements may be specified as certain paragraphs of applicable specifications. However, if special retest procedures are required, they shall be detailed in the RIB.

Retrofit or Repair Compliance forms are to be completed when the retrofit (or repair) is accomplished: see Figure 8. These forms are used to give detailed information regarding parts added and/or removed from NASA equipment.

DOCUMENT
CONTROL NO. ____________

NASA EXPERIMENT

____
Title

RETROFIT OR REPAIR COMPLIANCE REPORT

REPORTING FACILITY ____________________ DATE ______________ UNIT NO. __________

The following information must be submitted to the CSDL NASA Experiments Configuration Management office upon completion of any retrofit performed on ____________________ equipment.
Title

In Part I below list all components that are repaired and symbols or part number changes affecting subassembly and higher levels of equipment. All parts/assemblies added to or removed from airbourne equipment shall be listed in Part II using Part I item number as cross reference.

Part I Reparable Subassemblies/Black Boxes Affected.

REF. NO.	EQUIPMENT NAME	P/N PRIOR TO RETROFIT	EQUIP. S/N	RETROFIT INSTALLED			P/N AFTER RETROFIT	ADDITIONAL INFORMATION
				ECP NO.	KIT			
					P/N	S/N		

A - Added
R - Removed

	KIT INSTALLED	Q.A. VERIFICATION
DATE		
SIGNED		

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Figure 8

3.1.1.2 RIB Numbers

Each RIB number shall be a seven-digit NASA Production number (from a series assigned by the CMO). The RIBs will be written for the level of a highly skilled technician. Figure 9 is an outline of the format and types of information required in a RIB.

3.1.1.3 Contractor In-House Retrofit

RIBs are not required for contractor in-house retrofit. However, a retrofit kit drawing listing all parts and/or assemblies required to accomplish the retrofit must be processed through DRB and CCB. The elimination of RIBs for contractor in-house retrofit is predicated on the following actions:

(1) The Contractor is responsible to insure that adequate procedures are instituted and followed both internally and at subcontractors to properly accomplish these in-house retrofits.

(2) Retrofit kits with RIBs are still required for all field retrofits.

(3) Retest of modified equipment which consists of a complex functional test to the level of assembly modified is required.

(4) Deviation to item 3 shall be with the written prior concurrence of the NASA/MSC.

(5) All critical processing which has depotting, weld repairs, etc., shall be accomplished per CCB released ND documents or the procedure must be approved by the NASA/MSC.

3.1.2 Acceptance Data Package

Each deliverable retrofit kit shall require an Acceptance Data Package (ADP) to be delivered with the hardware. In addition, a Unit History Record shall accompany each article in accordance with MIT Report E-1087, "Documentation Handbook and Plan".

3.1.3 Drawings and Documents

All new drawings and revisions to documents necessary for the retrofit kit shall be prepared in accordance with MIT Report E-1167, "Drawing Standards", and shall be released through CCB by means of the ECR Procedure. The agency responsible for

RETROFIT INSTRUCTION BULLETIN (RIB) OUTLINE

I. PURPOSE

(A brief description of what the retrofit is to accomplish.)

II. AUTHORITY

(The ECP number.)

III. UNITS affected

(Name, part number, serial number, and new part number of the units to be modified, in indenture order.)

IV. PRIORITY CHANGES

(Any modification which must be incorporated prior to the incorporation of this retrofit.)

V. RELATED CHANGES

(Any other RIBs for the same ECP.)

VI. MATERIAL REQUIRED

(List of kit contents and a list of required, but not supplied, items, in indenture order of equipment affected.)

VII. PROCEDURE

(Instructions for accomplishment:

A. General-Applies to all sections if required or top kit retrofit procedure (Console, system, etc., of ECP); Statement of re-test requirements and procedures.

B., C., etc. - Section for each affected assembly of a console or specific instructions for the item for which there is a retrofit kit. Statement of re-test requirements and procedures.)

VIII. MODIFICATION DESIGNATION

(Application of new nameplates, marks, or harness tags for the console or end item. Console subassemblies will be given modification designation in their respective procedures.)

IX. DISPOSITION OF PARTS REMOVED

(Scrap, return to stock, etc.)

X. REPORT OF ACCOMPLISHMENT

Figure 9

maintenance of the master drawings shall establish two "top retrofit kit drawings" against which all retrofit kits will be released, i.e., one top kit drawing will be established for the release of all flight hardware kit assemblies and the other top kit drawing will be established for the release of all ground support equipment kit assemblies. The top retrofit kit drawings will list all applicable subkits necessary to modify components, assemblies, subassemblies, and spares. For each retrofit, a retrofit kit assembly drawing shall be established which shall contain a listing of all the subkit part numbers applicable to the ECP.

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CHAPTER 4

CONFIGURATION CONTROL IN MANUFACTURING

4.1 Purpose

This chapter refers to the Reliability and Quality Assurance system and procedures, the implementation of which will assure continuity of configuration control during the manufacture and production of hardware under NASA Experiment contracts.

4.2 Scope

This system is designed to provide the NASA with a high degree of confidence that the product, as represented by the delivered hardware, is of known and documented quality and free of problems associated with workmanship defects. This system provides for the accomplishment of the following objectives:

4.2.1 Design Review

That the design is reviewed for engineering excellence, quality, and reliability; and is subsequently controlled.

4.2.2 Parts Procurement Integrity

That parts and materials are procured from quality sources under appropriate quality requirements and that significant characteristics of this procured material are verified by inspection.

4.2.3 Material Control and Traceability

That material destined for inclusion in deliverable hardware is controlled and traceability maintained as to its history and status.

4.2.4 Manufacturing and Production

That fabrication and assembly operations are conducted in an organized and orderly fashion, with quality inspection of important hardware characteristics and workmanship, and that documented evidence exists of fabrication operations and inspections performed on hardware as it is processed.

4.2.5 Non-Conformance Monitoring

That non-conforming, discrepant material, and problems encountered throughout the process are documented, resolved, and corrective action effected.

4.2.6 Acceptance Data Collection

That hardware configuration, test data, and history, important to the sponsor's acceptance and uses, are accumulated and delivered with the units or collected for future availability.

4.3 Operation Procedures

The procedures listed hereafter are selected from the standard quality system developed at CSDL for implementation in an Engineering Research and Development environment. They have been selected to respond to the NASA requirements and special needs as imposed by the nature of the experiment projects.

4.3.1 Material Procurement, Supplier and Sub-Contractor Control - QOP 003 Revised June 9, 1970

4.3.2 Receiving, Inspection, Stocking, Issuance and Kitting - QOP 004 Revised June 9, 1970

4.3.3 Serialization and Lot Control - QOP 005 October 1969

4.3.4 Production and Inspection Planning and Control of Fabricated Articles - QOP 006 October 1969

4.3.5 Non-Conforming Material/Waivers - QOP 007 October 1969

4.3.6 In Process Inspection and Test - QOP 008 Revised May 13, 1970

4.3.7 Acceptance Data Package - QOP 010 Revised June 9, 1970

4.3.8 Handling of Government Furnished Equipment - QOP 014 Revised June 9, 1970

4.3.9 Calibration and Standards - QOP 012 October 1960

4.3.10 Failure Reporting and Corrective Action - QOP 011 Revised June 9, 1970

4.3.11 Qualification and Special Testing - QOP 016 May 15, 1970

4.3.12 Personnel Training and Certification - QOP 017 May 15, 1970

CHAPTER 5

GLOSSARY OF TERMS AND ABBREVIATIONS

5.1 Glossary of Terms

The following definitions shall apply to the use of terms as they appear in this publication.

Cancelled	"Cancelled" denotes any document which has been removed from potential use and which had not been released through the CCB at CSDL. The identification number of a cancelled document shall not be reassigned, and will not appear in formal documentation records.
Class of Changes	The classification of changes shall be in accordance with Section 2.7 of this publication
Dash Number	An identification suffix used to indicate a unique configuration of the hardware.
Deviation	A specific authorization, granted by NASA and CSDL before the fact, to depart from a particular requirement of specifications or related documents.
Effectivity	Effectivity identifies the application to stated designed CEI serial numbers.
ECP Form	The ECP form described in MIL-STD-480 shall be used as required. Refer to Section 2.9.2.
ECR Form	The ECR form (Figures 3 and 4) is used to authorize and release documentation through the CCB at CSDL.
Inactive	"Inactive" denotes any document which has been formally removed from use and the document had been previously released through the CCB at CSDL, and the document had previously been used to build, procure, test or otherwise support hardware.

Interchangeable Item	When two or more items possess such functional and physical characteristics as to be equivalent in performance, reliability, durability and capable of being exchanged one for the other without alteration of the items themselves or of adjoining item except for adjustment, and without selection for fit or performance, the items are interchangeable. Reference MIL-STD-447.
Obsolete	"Obsolete" denotes any document which has been formally removed from use, and the document had been previously released through the CCB at CSDL, build, procure, test or in any way support hardware.
Replacement Item	An item which is functionally interchangeable with another item, but which differs physically from the original part in that the installation of the replacement part required operations such as drilling, reaming, cutting, filing, shimming, etc., in addition to the normal application and methods of attachment, is known as a replacement item. Reference MIL-STD-447.
Revision Letter	An identification of the status of the document.
Schedule	Schedule is interpreted in accordance with the delivery requirements established by the contracts of the Contractors. Schedule impact identifies the fluctuation about these contractual delivery requirements.
Substitute	Where two or more items possess such functional and physical characteristics as to be capable of being exchanged only under certain conditions or in particular applications and without alterations of the items themselves or adjoining items they are substitute items. This includes the definition of one-way interchangeability such as, Item B can be interchanged in all applications for Item S, but Item A cannot be used in all applications requiring Item B. Reference MIL-STD-447.
Waiver	Granted use or acceptance by NASA and CSDL of an article which did not meet specified requirements. Reference NPC 200-2.

5.2 Abbreviations

The following abbreviations are used in this publication.

AGE/SE	Aerospace Ground Equipment/Support Equipment
APL	Advanced Parts List
ATS/P	Assembly Test Specification/Procedure
CCB	Configuration Control Board
CMO	Configuration Management Office
CSDL	Charles Stark Draper Laboratory
DRB	Design Review Board
ECP	Engineering Change Proposal
ECR	Engineering Change or Release
FSN	Federal Stock Number
FTM	Final Test Method
GFE	Government Furnished Equipment
ICD	Interface Control Document
JDC	Job Description Card
MRB	Material Review Board
NA	Not Applicable
PS	Procurement Specification
QA	Quality Assurance
RIB	Retrofit Instruction Bulletin
SCD	Specification Control Drawing

E-2509

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APPENDIX 8.1

SELECTED SEP PROJECT

TECHNICAL MEMOS

APPENDIX 8.1

SELECTED SEP PROJECT

TECHNICAL MEMOS

MEMO NO. I

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CENTER FOR SPACE RESEARCH
CAMBRIDGE, MASSACHUSETTS 02139

October 6, 1969

MEMORANDUM

TO: E. A. Johnston

FROM: W. W. Cooper

SUBJECT: Worst Case Dipole and Loop Efficiencies

DISTRIBUTION: R. H. Baker
L. H. Bannister
H. J. Nercessian

The efficiency of a very short dipole or loop depends on how it is matched to a load. For a worst-case broad-band design, with no attempt to match the reactive component of the antenna impedance, the efficiency is limited by the ratio of antenna radiation resistance to reactance. Even with matching of the antenna reactance, the efficiency is still limited by the ratio of radiation resistance to loss resistance.

Numerical values are given for a 1. meter diameter balanced dipole or loop of copper wire AWG #20 at 1. MHz.

For the 1. meter balanced dipole, the equation for radiation resistance is commonly known, and the loss resistance equals the r.m.s. current averaged over a unit triangular distribution in the wire, multiplied by the resistance per unit length (corrected for skin effect), multiplied by the length:

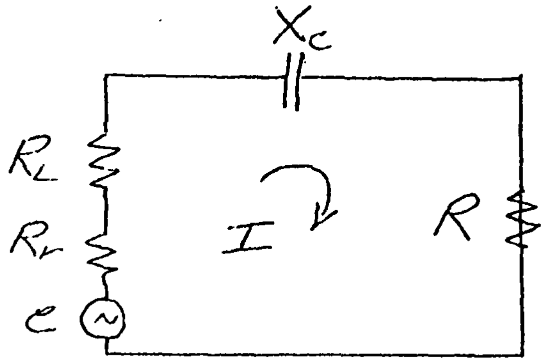
$$R_r = 20\pi^2 \ (L/\lambda)^2 = 2.194 \times 10^{-3}\Omega$$

$$R_L = (1/3)(.033\Omega/M)(3.3)(1.M) = 36.3 \times 10^{-3}\Omega$$

The reactance is approximately:

$$X_{in} \simeq -j19.1 \ \lambda/L = -j5.73 \times 10^3\Omega$$

Given the following equivalent circuit, the maximum power which can be transferred into the load and the efficiency follow directly:



$$P_R = \frac{1}{2}|I|^2 R \cong \frac{1}{2}|e|^2 R/(R^2 + X_{in}^2) \le |e|^2/4|X_{in}|$$

$$Pa \text{ (available power)} = |e|^2/4R_r$$

$$n = P_R/Pa \le R_r/|X_{in}| = .383 \times 10^{-6}$$

If the reactance could be matched at a single frequency, resulting in a Q greater than 10^5, then the maximum efficiency is:

$$n_{max} = R_r/(R_r + R_L) = .572 \times 10^{-1}$$

However, by operating at a more reasonable Q of 500, the dipole efficiency would be greater than 10^{-4} at 1. MHz.

For the 1. meter diameter loop, the efficiencies are significantly worse. Parenthetically, it may be noted that (i) in order to approximate a magnetic loop at 30 MHz, the loop should not be much larger than 1. meter diameter or .31λ circumference (ii) any attempt to use several turns of a coil at a smaller diameter would probably result in a grossly reduced efficiency. Similar calculations for the 1. meter loop at 1. MHz show that:

$$R_r = 20\pi^2(\pi D/\lambda)^4 = .237 \times 10^{-5}\Omega$$

$$R_L = \pi D(.033\Omega/M)(3.3) = .342\Omega$$

$$L_o \text{ (inductance)} \simeq \frac{\mu_o D}{2} \left[\ln\left(\frac{4D}{r}\right) - 2 \right] = 4.52\mu H$$

$$X_L \text{ (reactance)} = \omega L_o \simeq 28.4\Omega \text{ at } f = 1.\ \text{MHz}$$

reactive 'efficiency' = $R_r/X_L = .835 \times 10^{-7}$

maximum efficiency $\simeq R_r/R_L = .693 \times 10^{-5}$

Even with the low efficiency of the receiving loop, there should be adequate power to make a measurement. Assuming worst case numbers:

$$f = 1.\ \text{MHz}$$
$$\lambda = 300.\ \text{M}$$
$$\text{Range} = 3000.\ \text{M.}$$
$$\text{ERP} = 1.\ \text{Watt} = P_t G_t$$

we get:

$$P_a = \frac{3}{2} P_t G_t \left(\frac{\lambda}{4\pi \text{RANGE}}\right)^2 = .947 \times 10^{-4} \text{ Watt}$$

$$P_R = nP_a = .791 \times 10^{-11} \text{ Watt}$$

$$n = .835 \times 10^{-7}$$

With this 'untuned' antenna, we will take the noise in a band of 10^6 Hz, at a temperature of 1160°K:

$$N = KTB = 1.6 \times 10^{-14} \text{ Watt}$$

resulting in a margin of almost 30 dB.

Frequency dependence of short antenna efficiency

The relative efficiency of a short dipole or loop operating in the far zone of another antenna is maximized at a single frequency, ω_o, where the load resistance $R \simeq X$, the antenna reactance. In order to calculate the net received power, the frequency dependence of available power, ralative efficiency and absolute efficiency must be combined to give the following dependence on frequency, ω, (different from ω_o) dipole length, L, or loop diameter, D, effective radiated power, $P_t G_t$, and range R:

$$P_R(\omega|\omega_o) \simeq \frac{15\, P_t G_t}{16\pi\ 19.1c}\ \frac{\omega_o L^3}{R^2}\ \frac{2\omega^2}{\omega_o^2 + \omega^2}$$

(received power at ω dipole 'matched' at ω_o)

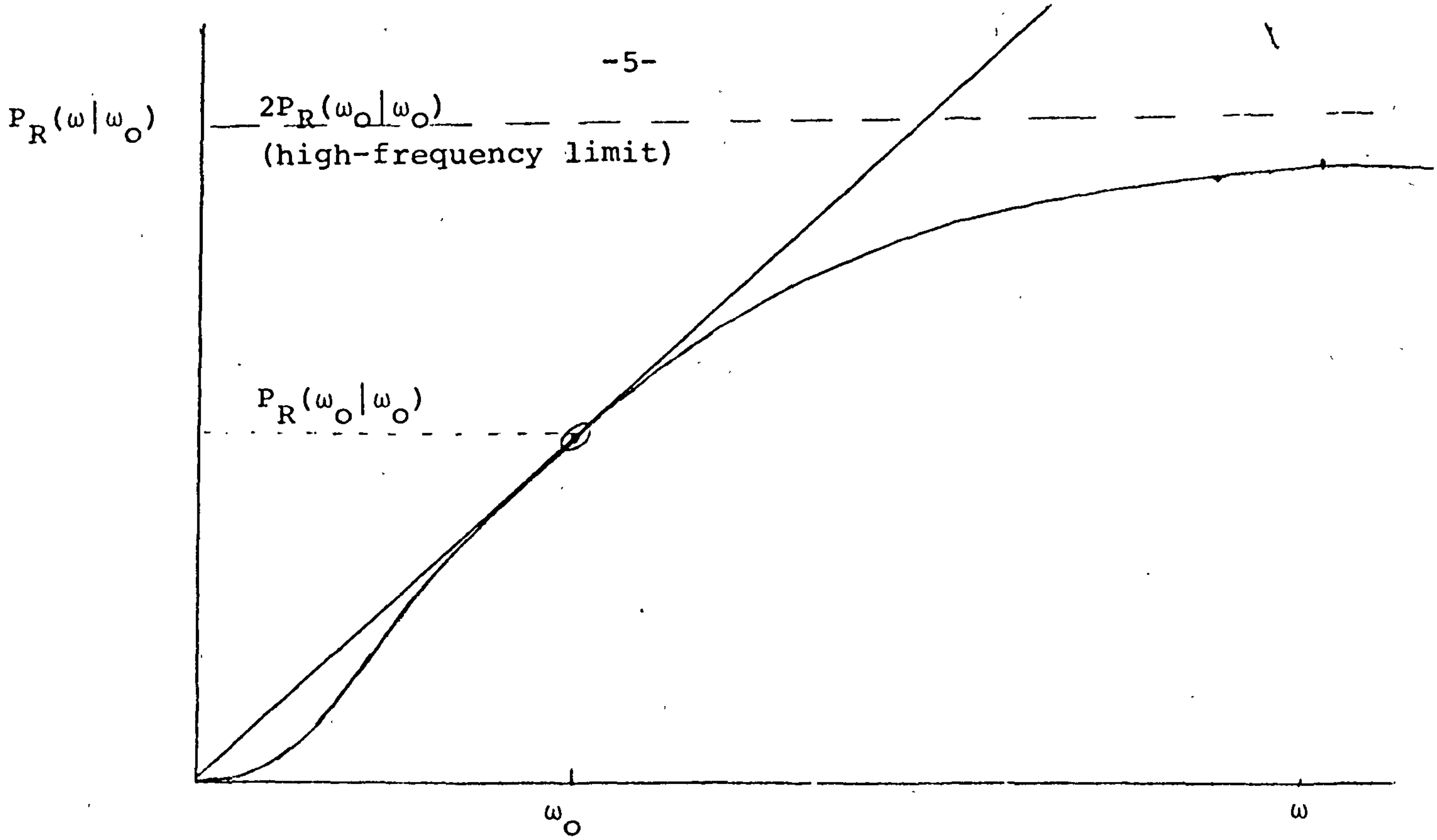
$$P_R(\omega|\omega_o) \simeq \frac{15\pi^2\, P_t G_t}{32c^2 \ell}\ \frac{\omega_o D^3}{R^2}\ \frac{2\omega^2}{\omega_o^2 + \omega^2}$$

(loop 'matched' at ω_o)

$$\ell \simeq \frac{\mu_o}{2}\left[\ell n\left(\frac{4D}{r}\right) - 2\right]$$

(inductance constant of wire)

The important feature of these formulas is not the absolute constants, which can be related to the numerical examples given above, but the dependence on frequency and antenna diameter. Note that the maximum power for a given ω is realized for $\omega_o \simeq \omega$, for which $P_R(\omega_o|\omega_o) = \omega_o L^3/R^2$. If ω_o is fixed, then P_R is quadratic for $\omega \to \infty$. Therefore, the above formulas for P_R have a universal behavior as illustrated below, in which the maximum received power is twice the low-frequency 'matched' power which is $\sim \omega_o L^3/R^2$.



To relate these formulas numerically to the above examples, suppose the previous 1. meter loop is cut to 1/3 meter and the frequency is reduced from f = 1. MHz to f = .5 MHz. Then the maximum received power at the worst case (lowest frequency = .5 MHz) is reduced by

$$\frac{\omega_o'}{\omega_o}\left(\frac{D'}{D}\right)^3 = \frac{1}{54}$$

or 17 dB, leaving a S/N margin of almost 10. dB.

It might be noted at this point that instead of scratching to make a transmitting antenna 1. or 2. dB more efficient, it might make more sense to introduce some tuning of the receiving antenna which could improve the signal 10. or 20. dB at the lowest frequency, and more at higher frequencies.

William W. Cooper

William W. Cooper

WWC:jmc

MEMO NO. II

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CENTER FOR SPACE RESEARCH
CAMBRIDGE, MASSACHUSETTS 02139

October 16, 1969

OCT 27 1972
J. W. MEYER

MEMORANDUM

TO: R. H. Baker

FROM: W. W. Cooper

SUBJECT: Possible Lunar Range-Azimuth Phase-Comparison System Using Three Transmitters and One Roving Receiver

DISTRIBUTION:

L. H. Bannister
J. Izumi
E. A. Johnston
H. J. Nercessian
R. Steendal

Introduction

As is fairly easily seen, it is impossible for a receiver to determine his position by comparison of signals from less than three independent transmitters unless (a) both the receiver and the transmitter have clocks which are synchronized to atomic accuracy (1. ns, $\sim$ 1. ft.) and/or (b) directional and/or polarized receiving antennae are used to discriminate between a direct wave and a wave reflected from an internal discontinuity in the lunar medium. In any case, it is impossible for a receiver to determine his azimuth with less than two transmitters unless the medium has very marked azimuthal asymmetry.

The basic idea is for the receiver to compare the time of arrival or phase of arrival of signals from three independent transmitters, and then to use a triangulation technique to determine the location of the receiver. This idea contains two basic assumptions:

(i) that the propagation of a wave through the lunar surface medium can be calculated accurately enough to relate phase retardation or time delay to range (with, say, .1 foot accuracy).

(ii) that the short-term phase, frequency, and time stability of the transmitters permit a measurement of relative retardation (with, say, .1 nanosecond).

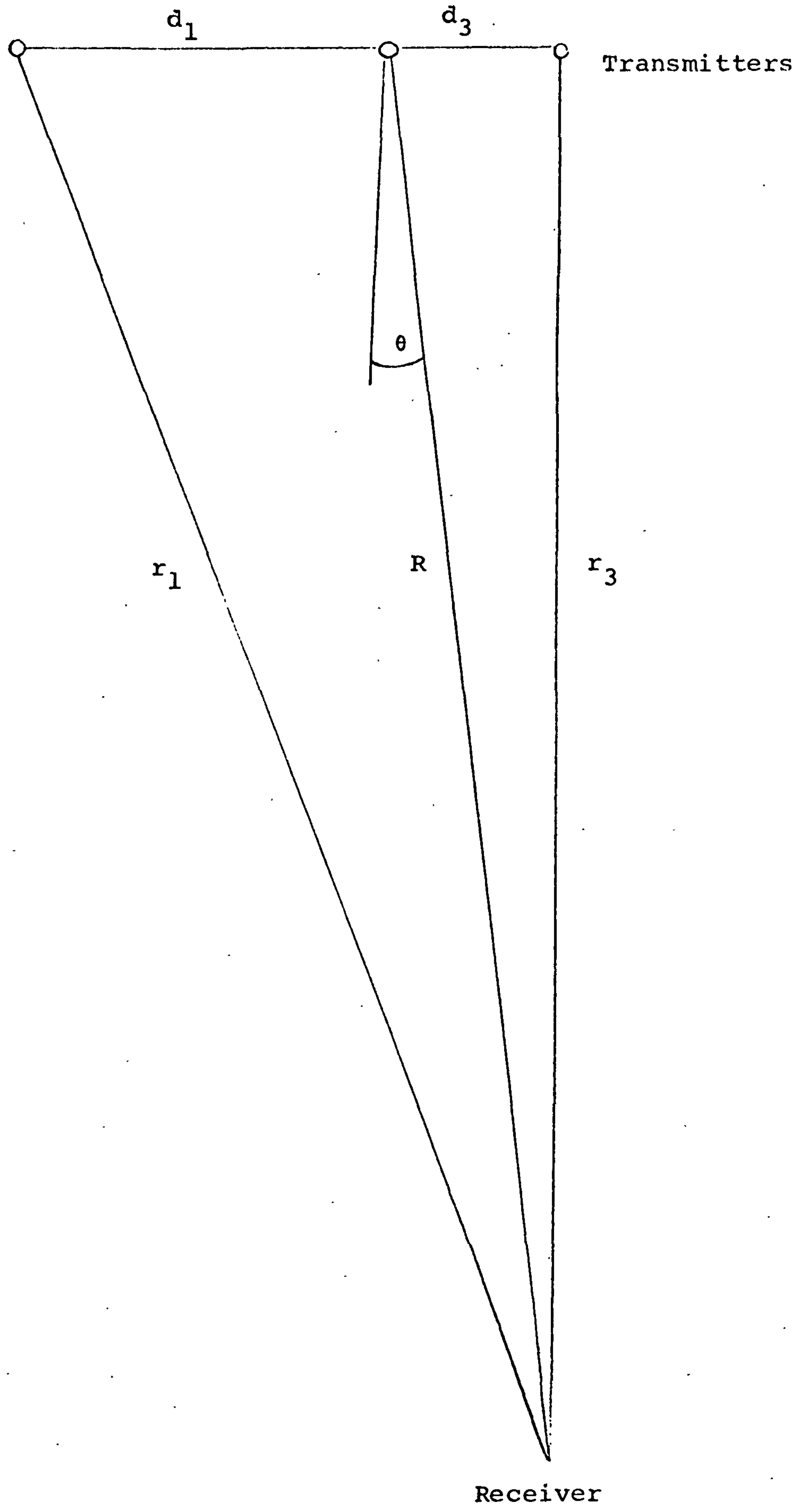
The propagation of an electromagnetic wave through an inhomogeneous medium cannot be discussed at the present time; this would require an investigation of the effects of surface roughness, lateral and vertical discontinuities, and the coupling of various transmitting and receiving antennae to the medium. Stability of the transmitter oscillator does not appear to be a major problem; in the implementation which is elaborated below, a narrowband phase comparison of signals from the three independent transmitters is proposed which requires only phase stability of about a degree over less than one r.f. cycle, and frequency stability consistent with the phase vs. range calculation.

Geometrical Considerations

Assuming that the differences in range from a receiver to three transmitters can be determined with a certain accuracy, the problem is to determine the accuracy of location of the receiver. Taking the case of three collinear transmitters with baselines d_1 and d_3, and a receiver at range R and azimuth θ from the central transmitter, as shown below; the problem is to relate the errors in the measurements of (r_1-R) and (r_3-R) to errors in range and azimuthal coordinates as follows:

$$r_1\, \delta r_1 = (R+d_1 \sin\theta)\delta R + d_1 \cos\theta \; R\delta\theta$$

$$r_3\, \delta r_3 = (R-d_3 \sin\theta)\delta R - d_3 \cos\theta \; R\delta\theta$$



d_1
d_3
Transmitters
θ
r_1
R
r_3
Receiver

Or

$$\begin{bmatrix} \delta(r_1-R) \\ \delta(r_3-R) \end{bmatrix} = \begin{bmatrix} \dfrac{R+d_1\sin\theta-r_1}{r_1} & \dfrac{d_1\cos\theta}{r_1} \\ \dfrac{R-d_3\sin\theta-r_3}{r_3} & \dfrac{-d_3\cos\theta}{r_3} \end{bmatrix} \begin{bmatrix} \delta R \\ R\delta\theta \end{bmatrix}$$

So

$$\begin{bmatrix} \delta R \\ R\delta\theta \end{bmatrix} = \frac{\begin{bmatrix} \dfrac{-d_3\cos\theta}{r_3} & \dfrac{-d_1\cos\theta}{r_1} \\ \dfrac{r_3+d_3\sin\theta-R}{r_3} & \dfrac{R+d_1\cos\theta-r_1}{r_1} \end{bmatrix}}{\dfrac{-\cos\theta}{r_1r_3}(d_1R+d_3R-d_3r_1-d_1r_3)} \begin{bmatrix} \delta(r_1-R) \\ \delta(r_3-R) \end{bmatrix}$$

For the case when $R \gg d_1, d_3$ one can expand

$$r_1 = (R+d_1) + d_1(\sin\theta-1)\left[1-\frac{d_1}{R}+\frac{d_1}{R}^2 - \cdots\right] - \left(d_1(\sin\theta-1)\right)^2\left[\frac{1}{2R}-\frac{3d_1}{2R}+\cdots\right]$$

$$r_3 = (R-d_3) - d_3(\sin\theta-1)\left[1+\frac{d_3}{R}+\frac{d_3}{R}^2+\cdots\right] - \left(d_3(\sin\theta-1)\right)^2\left[\frac{1}{2R}+\frac{3d_3}{2R^3}+\cdots\right]$$

So

$$\begin{bmatrix} \delta R \\ R\delta\theta \end{bmatrix} \approx \begin{bmatrix} \dfrac{-2r_1R}{d_1(d_1+d_3)\cos^2\theta} & \dfrac{-2r_3R}{d_3(d_1+d_3)\cos^2\theta} \\ \dfrac{r_1d_3}{d_1(d_1+d_3)\cos\theta} & \dfrac{-d_3d_1}{d_3(d_1+d_3)\cos\theta} \end{bmatrix} \begin{matrix} \delta(r_1-R) \\ \delta(r_3-R) \end{matrix}$$

Note that δR is $o(\text{parallax}^2)$ and $R\delta\theta$ is $o(\text{parallax})$.

To give a numerical example, suppose $d_1=d_3=30M.$, $R=3000M.$, then

$$\begin{bmatrix} \delta R \\ R\delta\theta \end{bmatrix} \simeq \begin{bmatrix} \dfrac{-10^4}{\cos^2\theta} & \dfrac{-10^4}{\cos^2\theta} \\ \\ \dfrac{50}{\cos\theta} & \dfrac{-50}{\cos\theta} \end{bmatrix} \begin{bmatrix} \delta(r_1-R) \\ \delta(r_3-R) \end{bmatrix}$$

so if $\delta R=30M \sim 100.ns.$, then $\delta(r_1-R)$ and $\delta(r_3-R)$ should be less than $\sim .01$ ns. If an r.f. carrier at 5 MHz were used, the corresponding errors of phase measurement should be less than:

$$.01 \times 10^{-9}\text{sec.} \times 360° \times 5 \times 10^{6}\text{sec}^{-1} = .018°$$

A Possible Implementation

A basic scheme is proposed in which phase is related to time by rotating the phase of one of the transmitters relative to the reference over a small range (say, 360°) during a relatively long time interval. By observing the amplitude of the combined signal (received from two of the transmitters) over a long time interval, the alternate constructive and destructive interference of the two received signals makes it possible to determine the relative phase retardation which is due to geometry alone (plus possibly systematic errors). Furthermore, it is proposed that only one of the transmitters and the reference transmitter be on simultaneously, so that the corresponding phase retardation (giving either (r_1-R) or (r_3-R) can be measured directly (without requiring impractical crystal filters to separate the three signals which might differ by only 1.Hz.).

So far, the proposal is relatively "machine-independent". The measurement of phase could be done either on the Earth after recording the received amplitude on tape, or on the Moon with analog circuits. The rotation of phase at the transmitter could be done either continuously or with small steps (say, 360°/16). It is recommended that the format of the signal from transmitter (1) be made significantly different from the signal at transmitter (3) (say, transmitter (2) is the reference). This format change could be made in several ways: (i) have transmitter (1) on for twice as long as transmitter (3) (ii) rotate the phase of transmitter (1) at twice the rate of transmitter (3) (iii) or many other format changes. It is recommended, however, that a transition from (1) to (3), or vice versa, a large discrete phase shift, of say $\pm$ 90°, be added to the signal to mark the transition (this should result in a large step in amplitude at the receiver, provided the receiver is not at a certain azimuth where the phases received from (1) and (3) would jump from $\pm$ 45° or from $\pm$ 135°. These azimuths could be arranged to be outside a most useful sector; e.g. near the axis of the collinear transmitters). The step in amplitude would mark a time origin from which time would be measured to points on the combined wave received from the two transmitters.

To give some numbers which are consistent with the above numerical example, suppose we wish to measure phase to .018° by rotating 360° over 1.0 second. This requires a time measurement to

$$\frac{.018^\circ}{360^\circ} = .5 \times 10^{-4} \text{ sec.}$$

Furthermore, this requires phase stability of $\sim$.018° over one r.f. cycle, and some minimum signal/noise ratio which still remain to be investigated (although 20 db. would probably give a safe margin for this example).

MEMO NO.III

ROTATING FIGURE-OF-EIGHT RADIATION PATTERN

A rotating figure-of-eight pattern can be generated by modulating the excitation currents of two orthogonal dipole antennas. Let i_a, i_b be the excitation currents of such a set of dipole antennas aa and bb, shown in Figure 1, such that,

$$i_a = \cos\alpha \; e^{j\omega t} \tag{1}$$

$$i_b = \sin\alpha \; e^{j(\omega t+\Delta)} \tag{2}$$

where:

ω is the carrier frequency

Δ is the relative phase shift at the carrier frequency

α is the modulating angle; $|\alpha(t) << \omega t|$

The corresponding normalized far electric-field components E_a and E_b will be,

$$E_a(t,\theta) = \cos\alpha \sin\theta \; e^{j\omega t} \tag{3}$$

$$E_b(t,\theta) = -\sin\alpha \cos\theta \; e^{j(\omega t+\Delta)} \tag{4}$$

where: θ is the azimuthal angle defined in Figure 1.

From (3) and (4), the resultant field pattern E_T is,

$$E_T = E_a + E_b = \left[\cos\alpha \sin\theta - \sin\alpha \cos\theta \; e^{j\Delta}\right] e^{j\omega t}$$

where $e^{j\omega t}$ is a common time dependence factor which can be dropped for analysis purposes, resulting in:

$$E_T = [\cos\alpha \quad \sin\theta - \sin\alpha \quad \cos\theta \quad \cos\Delta] - j \sin\alpha \quad \cos\theta \quad \sin\Delta = X - jY \tag{5}$$

where X, Y are the real and imaginary terms of E_T.

The maxima (or minima) of the pattern can be determined by taking a derivative of the radiated power with respect to the azimuthal angle (θ) and solving it for θ. The roots of θ determined thereby define the maximum and minimum of the pattern as described below.

$$\frac{\partial |E_T|^2}{\partial \theta} = \frac{\partial [E_T \cdot E_T^*]}{\partial \theta} = E_T \frac{\partial E_T^*}{\partial \theta} + E_T^* \frac{\partial E_T}{\partial \theta} = 0 \tag{6}$$

where:

$|E_T|^2 \triangleq E_T \cdot E_T^*$ is the radiated power

$$E_T^* = X + jY = [\cos\alpha \ \sin\theta - \sin\alpha \ \cos\theta \ \cos\Delta] + j\sin\alpha \ \cos\theta \ \sin\Delta \tag{7}$$

is the conjugate of E_T.

From (5),

$$\frac{\partial E_T}{\partial \theta} = [\cos\alpha \ \cos\theta + \sin\alpha \ \sin\theta \ \cos\Delta] + j\sin\alpha \ \sin\theta \ \sin\Delta = M + jN \tag{8}$$

where M, N are the real and imaginary parts of $\frac{\partial E_T}{\partial \theta}$

From (7),

$$\frac{\partial E_T^*}{\partial \theta} = [\cos\alpha \ \cos\theta + \sin\alpha \ \sin\theta \ \cos\Delta] - j\sin\alpha \ \sin\theta \ \sin\Delta = M - jN \tag{9}$$

From Equations (5) thru (9),

$$\frac{\partial |E_T|^2}{\partial \theta} = [X-jY][\bar{M}-jN] + [X+jY][\bar{M}+jN] = 0$$

$$XM - YN = 0 \qquad (10)$$

Substituting values of X, M, Y, N in (10),

$$[\cos\alpha \ \sin\theta - \sin\alpha \ \cos\theta \ \cos\Delta][\cos\alpha \ \cos\theta + \sin\alpha \ \sin\theta \ \cos\Delta]$$

$$-[\sin\alpha \ \cos\theta \ \sin\Delta] X [\sin\alpha \ \sin\theta \ \sin\Delta] = 0 \qquad (11)$$

which can be simplified to yield:

$$\tan 2\theta = \cos\Delta \frac{\sin 2\alpha}{\cos 2\alpha} = \cos\Delta \tan 2\alpha \qquad (12)$$

The roots of θ from (12) are given as,

$$\theta_\eta = \frac{1}{2} \tan^{-1} [\cos\Delta \ \tan 2\alpha] + \frac{\eta\pi}{2} \qquad (13)$$

For $\eta=0$, $\theta_o = \frac{1}{2} \tan^{-1} [\cos\Delta \ \tan 2\alpha]$ (14)

For $\eta=1$, $\theta_1 = \frac{1}{2} \tan^{-1} [\cos\Delta \ \tan 2\alpha] + \frac{\pi}{2} = \theta_o + \frac{\pi}{2}$ (15)

Field values at the two roots θ_o, θ_1 from (5), (14) and (15) are,

$$E_T(\theta_o) = [\cos\alpha \ \sin\theta_o - \sin\alpha \ \cos\theta_o \ \cos\Delta] - j\sin\alpha \ \cos\theta_o \ \sin\Delta \qquad (16)$$

$$E_T(\theta_1) = [\cos\alpha \ \cos\theta_o + \sin\alpha \ \sin\theta_o \ \cos\Delta] + j\sin\alpha \ \sin\theta_o \ \sin\Delta \qquad (17)$$

From (16) and (17)

$$|E_T(\theta_o)|^2 = \cos^2\alpha\ \sin^2\theta_o+\sin^2\alpha\ \cos^2\theta_o-2\sin\alpha\ \cos\alpha\ \sin\theta_o\ \cos\theta_o\ \cos\Delta \tag{18}$$

$$|E_T(\theta_1)|^2 = \cos^2\alpha\ \cos^2\theta_o+\sin^2\alpha\ \sin^2\theta_o+2\sin\alpha\ \cos\alpha\ \sin\theta_o\ \cos\theta_o\ \cos\Delta \tag{19}$$

From (18) and (19), $|E_T(\theta_1)|^2>|E_T(\theta_o)|^2$ which indicates that $E_T(\theta_1)$ is the maximum field and is separated from the minimum field $E_T(\theta_o)$ by 90° as shown in Figure 2. Replacing the dummy variable $\theta_o=\theta$, the maximum and minimum field expressions from (16) and (17) can be rewritten as,

$$E_{max}(\theta) = E_T(\theta_1) = (\cos\alpha\ \cos\theta+\sin\alpha\ \sin\theta\ \cos\Delta)+j\sin\alpha\ \sin\theta\ \sin\Delta \tag{20}$$

$$E_{min}(\theta) = E_T(\theta_o) = (\cos\alpha\ \sin\theta-\sin\alpha\ \cos\theta\ \cos\Delta)-j\sin\alpha\ \cos\theta\ \sin\Delta \tag{21}$$

Now let the ratio of minimum and maximum field amplitudes be defined as:

$$r \triangleq \left|\frac{E_{min}(\theta)}{E_{max}(\theta)}\right| \tag{21}$$

such that:

$$\frac{|E_{max}|^2-|E_{min}|^2}{|E_{max}|^2+|E_{min}|^2} = \frac{1-r^2}{1+r^2} \tag{22}$$

Substituting values of E_{max} and E_{min} from (18) and (19) in (22), results, after some manipulation, in:

$$\cos 2\theta\ \cos 2\alpha+\sin 2\theta\ \sin 2\alpha\ \cos\Delta = \frac{1-r^2}{1+r^2} \tag{23}$$

Substituting cosΛ from (12), in (23) then yields:

$$\cos 2\alpha = \frac{1-r^2}{1+r^2}\cos 2\theta \tag{24}$$

Equations (12) and (24) relate the four variables r, θ, α and Λ controlling the behavior of the rotating radiation pattern. The plots of these equations are periodic in nature and possess symmetry about $\Delta = \frac{\pi}{2}$ and $\alpha = \frac{\pi}{4}$ axes as shown in Figure 3. Because of symmetry, all pertinent information is contained in the range $0 \leq \alpha \leq \frac{\pi}{4}$ and $0 \leq \Delta \leq \frac{\pi}{2}$. Furthermore, it can be seen that for any two prescribed parameters of the required rotating pattern, the remaining variables can be determined from Figure 3.

For example, suppose it is required to generate a rotating pattern with a rotation rate of 15 revolutions per second and with 80% modulation (r=0.2). In such a case, the azimuth angle $\theta(t)=2\pi$ is scanned in 6.66×10^{-2} seconds. For graphical convenience, let this time interval be divided into 32 intervals each of duration $t = 2.062 \times 10^{-3}$ seconds corresponding to an angular change of $\frac{\pi}{16}$. Using the plots of Figure 3, the corresponding values of Δ and α can be determined and are drawn in Figure 4. An electronic implementation of these values will generate the desired 15 revolutions per second rotation rate.

Two special cases of interest can be inferred directly from Figures 2 and 3.

(a) For 100% modulation (r=0) the contour lies on the abcissa which means $\Delta=0$ and $\alpha=\theta$. This implies that to realize a rotating beam in case c in Figure 2, no relative phase shift in the carrier frequency is required or allowed. The antenna excitation current angle α will be synchronous with the azimuthal angle θ of the rotating beam. The electronic hardware in the transmitter designed for the Surface Electrical Properties experiment has been designed to operate in this 100% modulation mode.

(b) For the zero percent modulation case (r=1), $\Delta=\frac{\pi}{2}$ and $\alpha=\frac{\pi}{4}$. This is the special case represented by the conventional turnstile antenna.

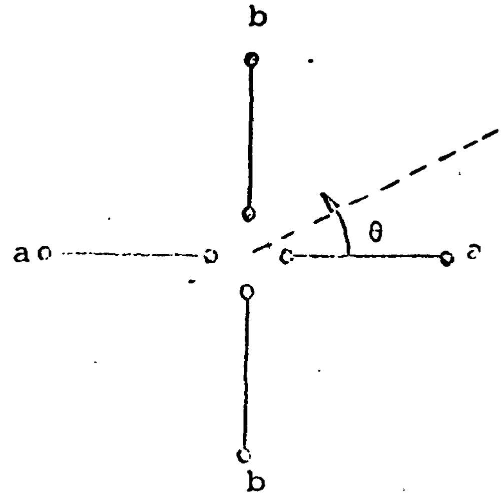


Figure 1. Set of Two Orthogonal Dipoles Antennas

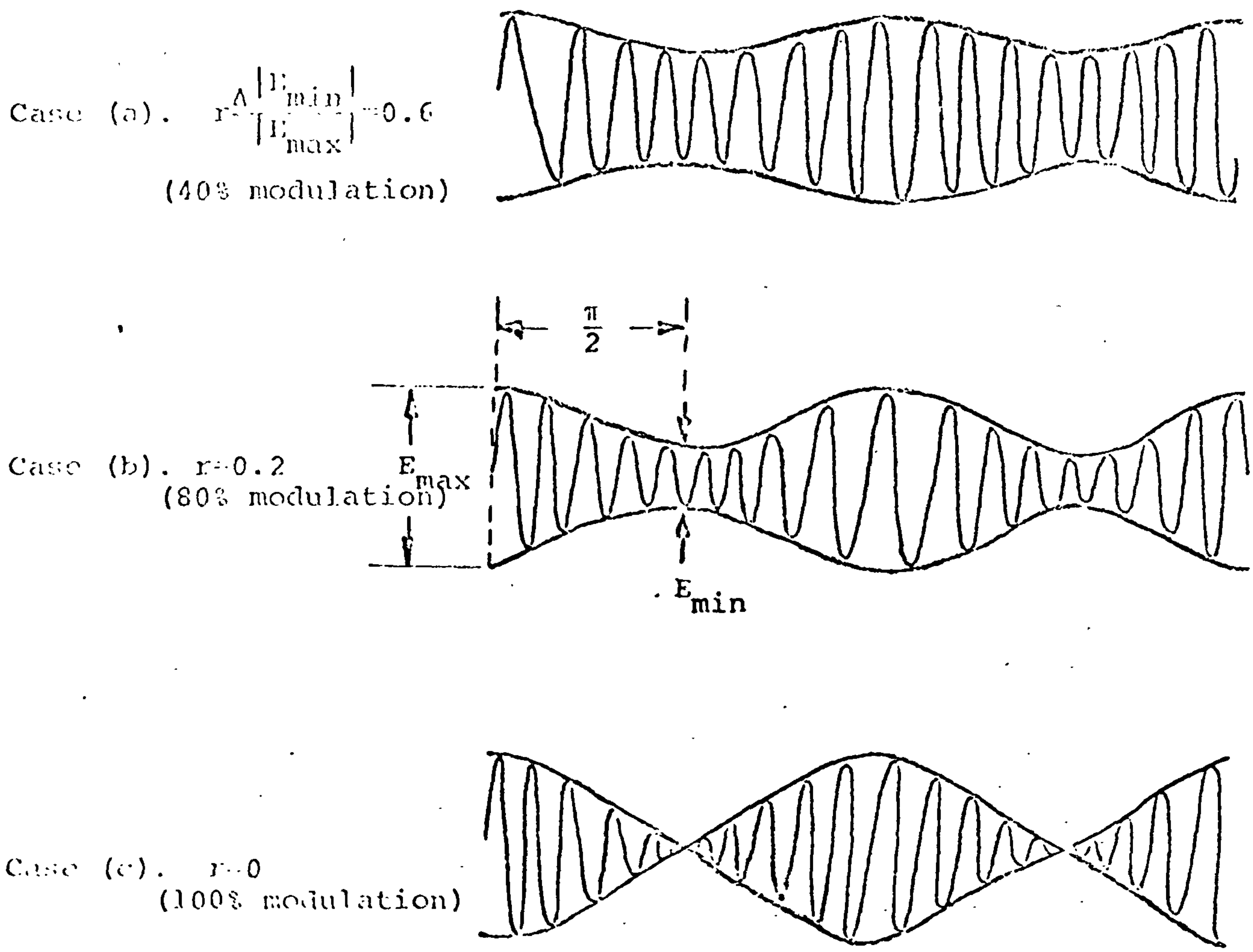


Figure 2. Maximum and Minimum of Electric Field for Rotating Radiation Pattern

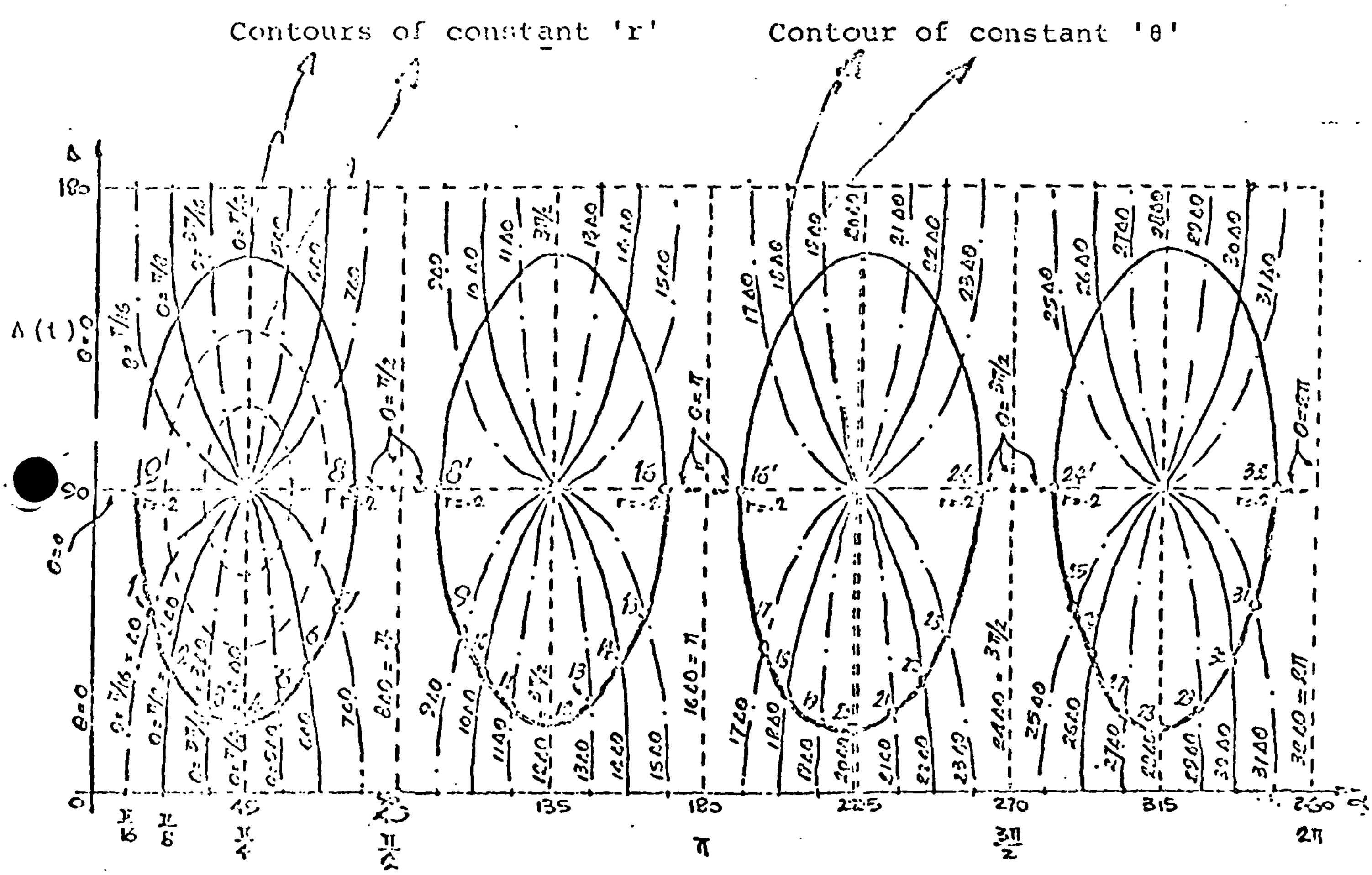


Figure 3. Plots Relating the Variables r, θ, Δ, α

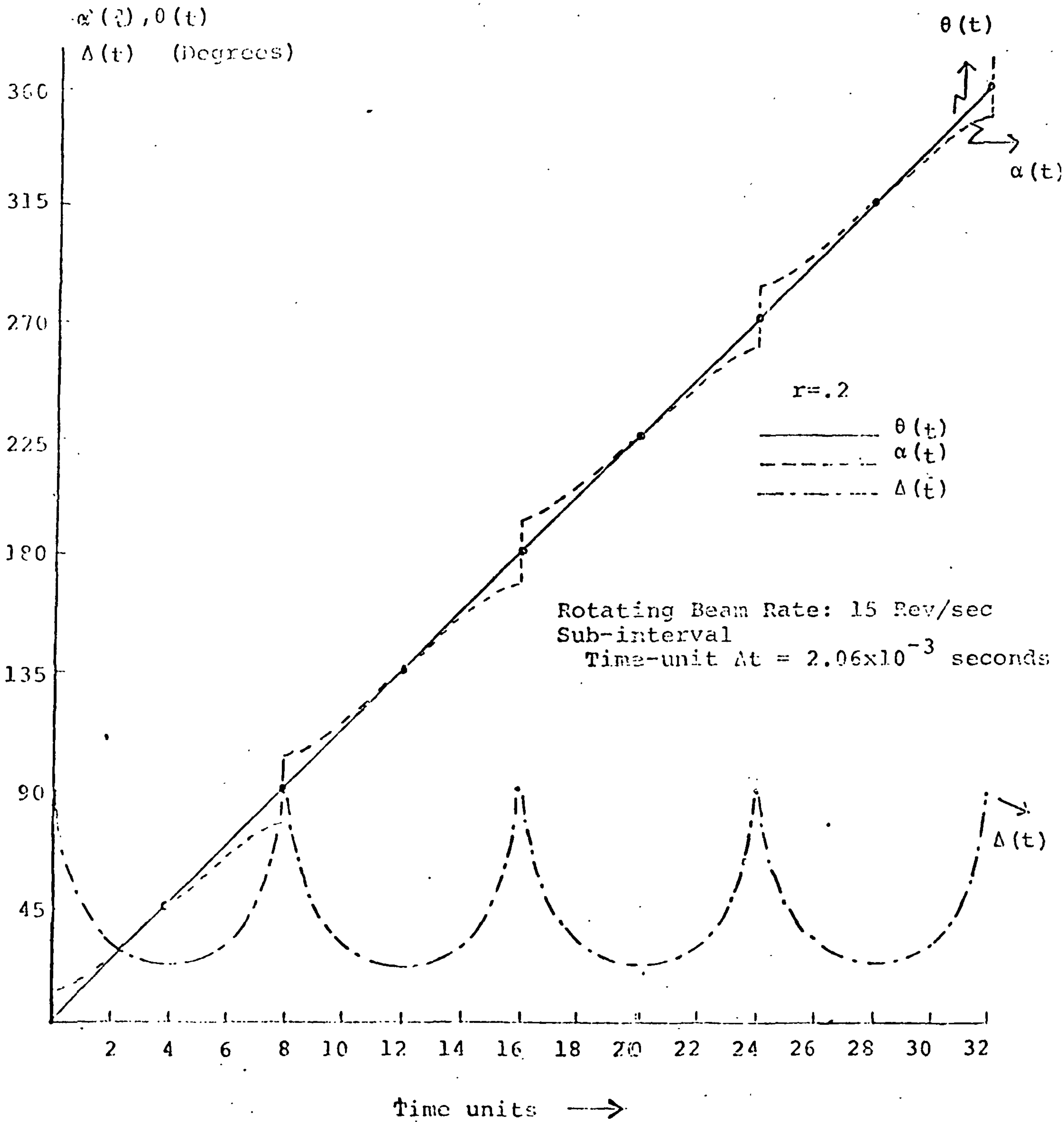


Figure 4. Parameter Values for 80% Modulated,
15 Revolutions per second Rotating Pattern

MEMO NO. IV

TO: R. H. Baker

FROM: V. P. Nanda

SUBJECT: Nature of Dielectric Losses and Dissipative Attenuation of R. F. Waves in a Lossy Medium

When an electric field is incident on a dielectric medium, it can cause three types of polarizations, i.e.,

(i) Electronic polarization due to displacement of orbital electrons.

(ii) Atomic polarization.

(iii) Molecular polarization.

The end result is that electric flux density D (also called displacement) in the dielectric medium is different from the incident electric field. For the static electric case, it is know that

$$D_s = E_s + 4\pi P = k_e K_s \qquad (7)$$

where:

D_s is the displacement or electric flux density in the medium.

E_s is the static electric field.

K_e is a constant (characteristic of the medium).

P is the total polarization of medium, i.e. electric dipole moment/unit volume.

When an RF time harmonic field E is incident on a dielectric medium, the polarization P also varies with time and so does the displacement D. However, at higher frequencies P and D may lag behind in phase relative to E and this hysteresis factor accounts for losses in a dielectric medium as shown below.

$$\text{Let } E = E_o e^{j\omega t} \tag{8}$$

such that displacement D is given by

$$D = \varepsilon E e^{-j\delta} \tag{9}$$

where:

δ is the lag angle between the incident field and displacement D.

ε is the permitivity of the medium.

E_o is the maximum amplitude of the incident RF wave

From (9),

$$D = (\varepsilon \cos \delta - j \varepsilon \sin \delta) E$$

$$D = (\varepsilon' - j\varepsilon'') E \tag{10}$$

$$\text{such that } \tan \delta = \frac{\varepsilon''}{\varepsilon'} \tag{11}$$

The energy dissipated per unit volume per second in the medium in form of heat is

$$W \triangleq \frac{1}{T} \int_0^T R_e(VI)\, dt \tag{12}$$

where $R_e(V)$ is the real part of rf voltage across unit distance $\triangleq \int_o^1 R_e(E) \cdot dx = E_o \cos \omega t$ (13)

$T = \frac{\omega}{\pi}$ is the time period of the incident wave

$R_e(I)$ is the real part of the displacement current

$$\triangleq \frac{dq}{dt} = \frac{1}{4\pi}\frac{dD}{dt} = \frac{\omega E_o}{4\pi} \left(\varepsilon'' \cos\omega t - \varepsilon' \sin\omega t\right) \tag{14}$$

From (12), (13), and (14), the energy dissipation in the dielectric media is given by:

$$W = \frac{1}{T}\int_0^T \frac{\omega E_o^2}{4\pi} \left(\varepsilon'' \cos\omega t - \varepsilon' \sin\omega t\right) \cos\omega t \, dt$$

$$W = \frac{\omega E_o^2}{8\pi}\, \varepsilon'' \tag{15}$$

Thus losses in the dielectric medium are dependent on ε'', the imaginary part of the dielectric constant. The loss tangent ($\tan\delta$) is a measure of the energy dissipated to the energy stored in the medium. Furthermore, it can be said that both ε' (ω,θ) and ε'' (ω,θ) are frequency and temperature dependent. Physical explanation is that frequency and temperature variations create disalignment and lag of polarized dipoles. For a non-polar medium ε' (ω) remains practically constant over a wide frequency range and ε'' (ω) is of relatively small magnitude. The losses in the dielectric medium are ohmic in nature and can be associated with the conductivity, σ, of the medium.

DISSIPATIVE ATTENUATION OF RF WAVES IN A LOSSY MEDIUM

A plane R.F. wave propagating in a lossy medium in the positive z direction is represented as

$$E(z) = E_o\, e^{-jKz} \tag{16}$$

where:

E_o is the electric field amplitude at $z = 0$

K is the propagation constant; a complex number

For a simple case, it can be assumed that the medium is homogeneous, isotropic, linear and non-magnetic. The propagation constant K is given by

$$K \triangleq \omega\sqrt{\mu\varepsilon} \tag{17}$$

where:

$\mu = \mu' - j\mu'' = \mu o$ for a lossless, non-magnetic medium

$\varepsilon = \varepsilon' - j\varepsilon''$ is the complex permitivity of the lossy dielectric medium (18)

From (17) and (18),

$$K = \omega\sqrt{\mu o(\varepsilon' - j\varepsilon'')} = \omega\sqrt{\mu o\varepsilon'}\,\left[1 - j\frac{\varepsilon''}{\varepsilon'}\right]^{\frac{1}{2}}$$

$$= \omega\sqrt{\mu o\varepsilon'} - j\omega\frac{\sqrt{\mu\varepsilon'}}{2}\tan\delta \tag{19}$$

where:

$\tan\delta$ = loss tangent of medium $\triangleq \frac{\varepsilon''}{\varepsilon'}$

and $\varepsilon'' << \varepsilon'$

Substituting $\sqrt{\varepsilon'} = \sqrt{k_e \varepsilon_o}$ in (19),

$$K = \frac{2\pi}{\lambda}\sqrt{k_e} - j\,\frac{\pi}{\lambda}\sqrt{k_e}\,\tan\delta \tag{20}$$

where:

k_e is the dielectric constant of medium

λ is the free space wavelength

$\frac{2\pi}{\lambda}\sqrt{k_e}$ is the phase constant of the medium

$\frac{\pi}{\lambda}\sqrt{k_e}\,\tan\delta$ is the attenuation constant of the medium

From (20) and (16), the propagating electric field $E(z)$ at distance z is given by

$$E(z) = E_o\, e^{-\frac{\pi}{\lambda}\sqrt{k_e}\tan\delta\, z}\; e^{j\frac{2\pi}{\lambda}\sqrt{k_e}\, z} \tag{21}$$

At distances $z = 0$ and z_1, from (21)

$$|E(0)| = E_o \tag{22}$$

$$|E(z_1)| = E_o\, e^{-\frac{\pi}{\lambda}\sqrt{k_e}\tan\delta z_1} \tag{23}$$

Therefore, the dissipative attenuation α_D in db at distance z_1, from (22) and (23) is,

$$\alpha_D(z_1) \triangleq 20\log\left|\frac{E(0)}{E(z_1)}\right| = 27.26\,\frac{\sqrt{k_e}\tan\delta}{\lambda}\, z_1 \text{ db} \tag{24}$$

Equation (24) is the basic equation used to compute dissipative attenuation (α_D) for varying parameters. It also indicates that a linear relationship exists between the loss tangent and the dissipative attenuation for the considered medium.

For ready reference attenuation calculations for various cases are listed below.

Case (1): For $z_1 = \lambda$; $\tan\delta = 0.01$; $k_e = 9$,

$$\alpha_D(\lambda) = 0.818 \text{ db}/\lambda \tag{25}$$

Case (2): for $z_1 = \lambda$; $\tan\delta = 0.05$, $k_e = 9$,

$$\alpha_D(\lambda) = 4.09 \text{ db}/\lambda \tag{26}$$

Case (3): for 0.5 MHz $\leq f_o \leq$ 32 MHz; 0.01 $\leq \tan\delta$

$\leq$ 0.05 z_1 = 1 Kilometer; k_e = 9

FREQUENCY (MHz)	ATTENUATION	
	Tan δ = 0.01 $\alpha_D(\lambda)$=.818db/λ	Tan δ = 0.05 $\alpha_D(\lambda)$=4.09db/λ
0.5 MHz	1.35 db/kilometer	6.82 db/kilometer
1 "	2.73 "	13.63 "
2 "	5.45 "	27.26 "
4 "	10.9 "	54.52 "
8 "	21.81 "	109.04 "
16 "	43.62 "	218.08 "
24 "	65.42 "	327.12 "
32 "	87.23 "	436.16 "

To conclude, the excess attenuation suffered by a wave propagating in a lossy medium is given by:

$$\alpha = 81.8 \frac{L_t}{\lambda} \tan\delta \tag{27}$$

where α is the excess attenuation, in decibels

L_t is the length of the transmission path, in meters

λ is the free space signal wavelength, in meters

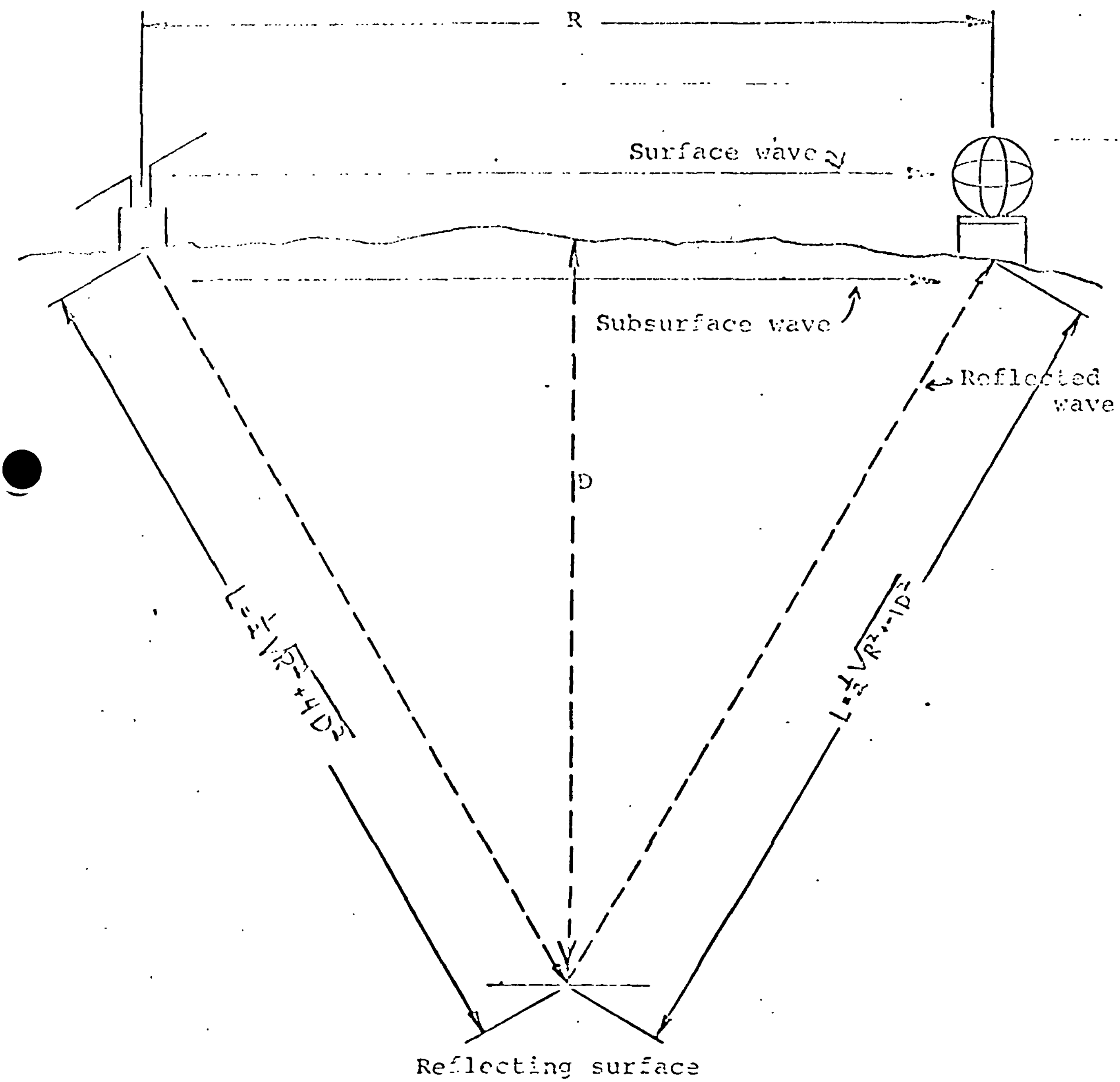
$\tan\delta$ is the loss tangent characteristic of the transmission medium

It is expected that the loss tangent for the lunar material, in situ, will range from 0.01 to 0.05; accordingly, the excess attenuation will be:

$$0.818 \leq \alpha \leq 4.09 \text{ db/wavelength} \tag{28}$$

From Figure 1 one can guess that the received field strength which is the complex interference pattern of the surface, subsurface and reflected waves will vary as a function of frequency, range, depth dielectric properties of the lunar material (both electrical and mechanical), etc. Even the surface wave (air wave component of the field will most likely be dependent upon the surface terrain. Accordingly, the signal levels shown in Figures 2 through 4 are only typical of what might be expected. It is on these calculated results, however, that the experiment configuration is based. We are currently working to verify these theoretical results with quantitative experimental data from glacier trials.

Pertinent experimental geometry and an idealized view of the signal paths.



$P_{surface} \propto K\frac{1}{4\pi R^2}$

$P_{reflected} \propto K[\frac{1}{4\pi R^2}] - \alpha L$

$P_{subsurface} \propto K[\frac{1}{4\pi R^2}] - \alpha R$

Figure 1

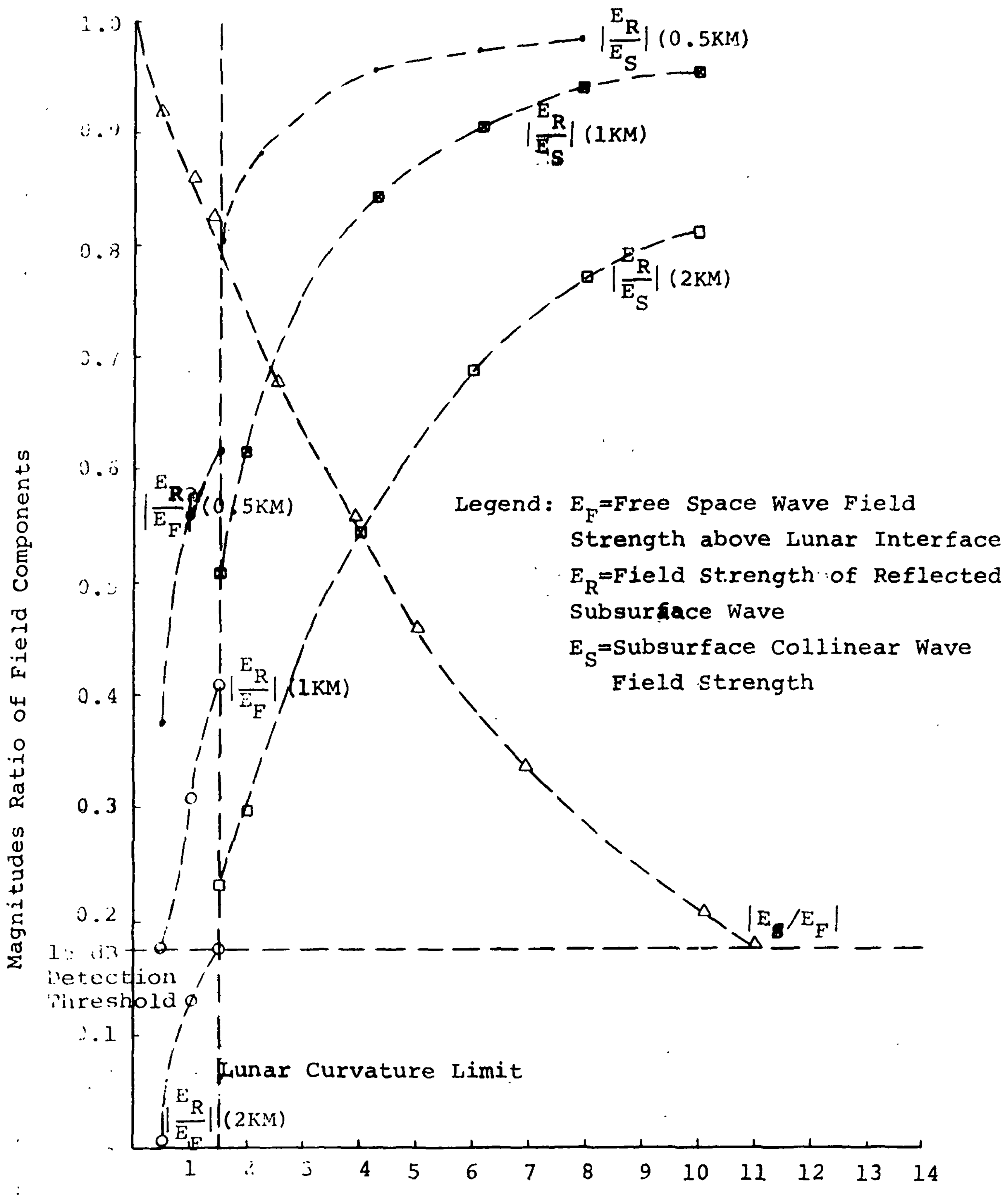


Figure 3. Relative Field Strengths versus Range for Varying Lunar Depths @ $\tan\delta=0.01$, $k_e=9$ and $F_0=0.5$ MHz

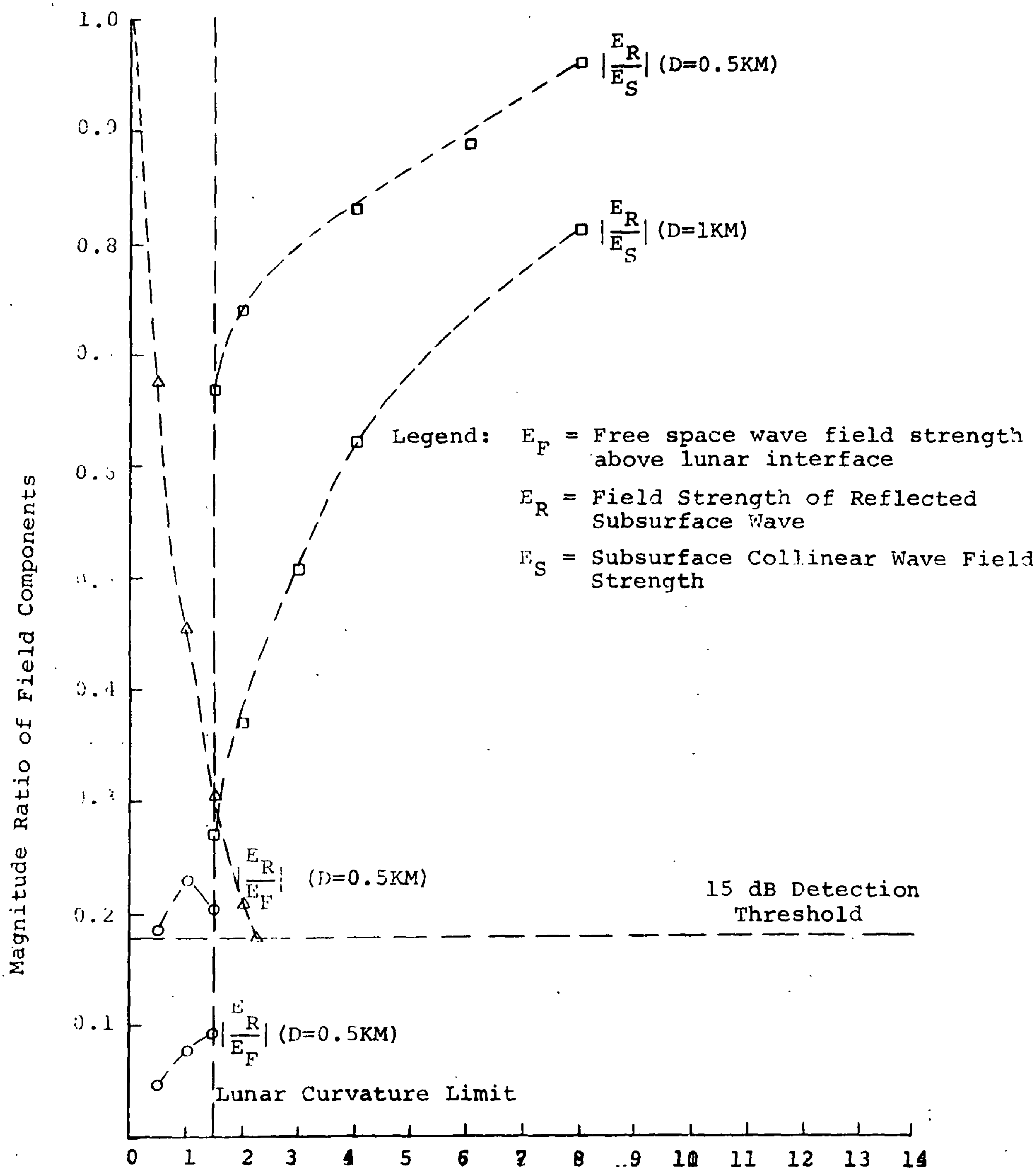
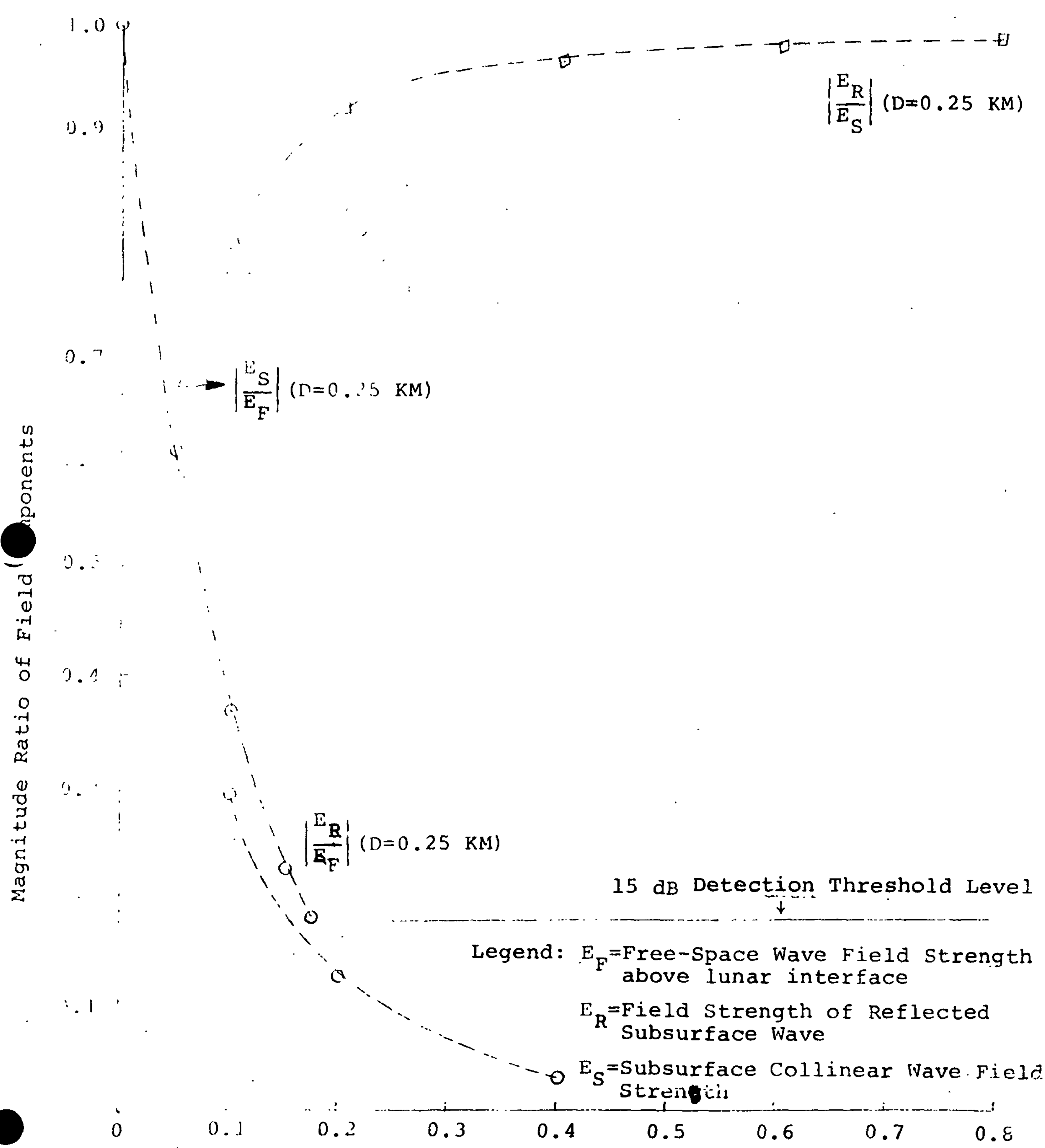


Figure 3. Relative Field Strengths, vs. Range for Varying Lunar Depths @ tanδ=0.05, $\overline{k_e}$=9, f_0=0.5 MHz.

Figure 4. Relative Field Strengths versus Range
@ f_0=32 MHz; tanδ=0.01; depth =0.25 kilometer
ke =9



MEMO NO. V

Generalized Considerations of RF Interference Pattern

and

Extraction of Range Information

1.1 General Derivation

For a transmitting system (T_X) deployed at the free-space/ dielectric-medium half-space interface, the r.f. power received at the interface point R_X is mainly due to three modes of propagation as shown in Figure 1 geometry. The propagating fields for these modes can be expressed in one of the following general forms;

$$E_f = \frac{A}{R} e^{-j(wt+\theta_1)} \tag{1}$$

$$E_s = \frac{B}{R} e^{-\alpha R+j(wt+\theta_2)} \tag{2}$$

$$E_r = \frac{Ce^{-\alpha R_3+j(wt+\theta_3)}}{R_3} \tag{3}$$

where:

E_f = Propagating field in free space

E_s = Collinear subsurface propagating field below the interface

E_r = Reflected subsurface propagating field

R = Propagating distance for free space and collinear subsurface wave

R_3 = Propagating distance for reflected subsurface wave (4)
$\approx [R^2+4D^2]^{1/2}$ where D = Average depth of the reflecting layer

w = Angular frequency of the r.f. source

t = Time duration

α = Average attenuation constant of the dielectric medium

$$= \frac{\pi}{\lambda} \sqrt{ke} \tan\delta$$

$\theta_1 = \beta_1 R = \frac{2\pi}{\lambda_1} R$ = Phase delay of free space wave

$\theta_2 = \beta_2 R = \frac{2\pi}{\lambda_2} R$ = Phase delay of collinear subsurface wave (6)

$\theta_3 = \beta_2 R_3 = \frac{2\pi}{\lambda_2} R_3$ = Phase delay of reflected subsurface wave

$\beta_2 = \sqrt{ke}\ \beta_1$; β_1, β_2 are phase constants of free space and dielectric medium (7)

λ_1, λ_2 = Wavelengths in free space and dielectric medium

ke = Average dielectric constant of the medium

A,B,C = Field amplitude parameters for the three modes

Total Field (E_T) observed at the interface for a single reflection case will be the summation of E_f, E_s, and E_r such that,

$$E_T = R_e\left[\frac{A}{R} e^{-j(wt+\theta_1)} + \frac{B}{R} e^{-\alpha R+j(wt+\theta_2)} + \frac{C}{R_3} e^{-\alpha R_3+j(wt+\theta_3)}\right.$$

$$E_T = \frac{A}{R} \cos (wt+\theta_1) + \frac{B}{R} e^{-\alpha R} \cos(wt+\theta_2) + \frac{C}{R_3} e^{-\alpha R_3} \cos(wt+\theta_3) \qquad (8)$$

$$E_T = \frac{A}{R} [\cos wt \cos \theta_1 - \sin wt \sin \theta_1] + \frac{B}{R} c^{-\alpha R} [\cos wt \cos \theta_2 - \sin wt \sin \theta_2] + \frac{C}{R_3} e^{-\alpha R_3} [\cos wt \cos \theta_3 - \sin wt \sin \theta_3]$$

$$E_T = \cos wt \left[\frac{A}{R} \cos \theta_1 + \frac{B}{R} e^{-\alpha R} \cos \theta_2 + \frac{C}{R_3} e^{-\alpha R_3} \cos \theta_3\right] - \sin wt \left[\frac{A}{R} \sin \theta_1 + \frac{B}{R} e^{-\alpha R} \sin \theta_2 + \frac{C}{R_3} e^{-\alpha R_3} \sin \theta_3\right]$$

$$|E_T| = [\frac{A^2}{R^2} + \frac{B^2}{R^2} e^{-2\alpha R} + \frac{C^2}{R_3{}^2} e^{-2\alpha R_3} + \frac{2AB}{R^2} e^{-\alpha R} \cos\theta_1 \cos\theta_2 +$$

$$\frac{2BC}{RR_3} e^{-\alpha(R+R_3)} \cos\theta_2 \cos\theta_3 + \frac{2AC}{RR_3} e^{-\alpha R_3} \cos\theta_3 \cos\theta_1 +$$

$$\frac{2AB}{R^2} e^{-\alpha R} \sin\theta_1 \sin\theta_2 + \frac{2BC}{RR_3} e^{-\alpha(R+R_3)} \sin\theta_2 \sin\theta_3 +$$

$$\frac{2CA}{RR_3} e^{-\alpha R_3} \sin\theta_3]^{1/2}$$

$$|E_T| = [\frac{A^2}{R^2} + \frac{B^2}{R^2} e^{-2\alpha R} + \frac{B^2}{R_3{}^2} e^{-2\alpha R_3} + \frac{2AB}{R^2} e^{-\alpha R} \cos(\theta_2-\theta_1) +$$

$$\frac{2BC}{RR_3} e^{-\alpha(R+R_3)} \cos(\theta_3-\theta_2) + \frac{2AC}{RR_3} e^{-\alpha R_3} \cos(\theta_3-\theta_1)]^{1/2} \quad (9)$$

No generality is lost by substituting $B = x A$ and $C = yA$ in (9) such that normalized amplitude $|E_T^N|$ is

$$|E_T^N| \approx \left|\frac{E_T}{A}\right| = [\frac{1}{R^2} + \frac{x^2}{R^2} e^{-2\alpha R} + \frac{y^2}{R_3{}^2} e^{-2\alpha R_3} + \frac{2x}{R^2} e^{-\alpha R} \cos(\theta_2-\theta_1) +$$

$$\frac{2xy}{RR_3} e^{-\alpha(R+R_3)} \cos(\theta_3-\theta_2) + \frac{2y}{RR_3} e^{-\alpha R_3} \cos(\theta_3-\theta_1)]^{1/2} \quad (10)$$

where: $x = B/A$ = ratio of amplitudes of collinear subsurface waves and free-space waves

$y = C/A$ = ratio of amplitudes of reflected wave and free-space waves

1.2 Interpretting General Expression

Equation (10) is the generalized expression for the interference pattern at the half-space interface. The first three terms $\frac{1}{R^2}$, $\frac{x^2}{R^2} e^{-2\alpha R}$ and $\frac{y^2}{R_3^2} e^{-2\alpha R_3}$ represent the decreasing field strength with propagating of the three modes E_f, E_s, and E_r respectively whereas the remaining three terms signify the mutual interference contributions.The sum $\left[S_m = \left\{\frac{1}{R^2} + \frac{x^2}{R^2} e^{-2\alpha R} + \frac{y^2}{R_3^2} e^{-2\alpha R_3}\right\}^{1/2}\right]$ monotonically decreases with increasing distance from the rf source and represents the resultant field amplitude when the interference terms pass through the zero crossover points. Range information can be derived from the monotonic plot of the sum of these terms. The maxima and minima in the interference pattern is generated whenever the interference terms add and substract from the sum S_m for discrete values of range R.

1.3 Implications of Interference Terms

1.3.1 Term $\frac{2x}{R^2} e^{-\alpha R} \cos(\theta_2 - \theta_1)$

This term originates due to interaction between the free space and collinear subsurface propagating waves. The condition for maxima is:

$$\cos(\theta_2 - \theta_1) = \cos 2\pi m \tag{11}$$

such that range distances for maxima (R_m) are

$$R_m = \frac{m\lambda_1}{\sqrt{ke} - 1} \tag{12}$$

where m = 1, 2, 3,

Similarly, condition for minima range distances is

$$\cos\ (\theta_2-\theta_1) = \cos\ (2n+1)\pi \tag{13}$$

$$Rn = \frac{(2n+1)\lambda_1}{2[\sqrt{ke}\ -1]} \tag{14}$$

where n = 0, 1, 2, 3

The ranges at crossover points are governed by the condition

$$\cos\ (\theta_2-\theta_1) = \cos\ (2k+1)\ \frac{\pi}{2} \tag{15}$$

$$R_k = \frac{(2k+1)\lambda_1}{4[\sqrt{ke}\ -1]} \tag{16}$$

where k = 0, 1, 2, 3

The separation distance ΔR between successive maxima or minima is given as:

$$\Delta R = \frac{\lambda_1}{[\sqrt{ke}\ -1]} \tag{17}$$

1.3.2 Term $\frac{2xy}{RR_3}\ e^{-\alpha(R+R_3)}\ \cos\ (\theta_3-\theta_2)$

It represents the interaction between surface and subsurface waves of the dielectric medium.

The condition for maxima of this term is:

$$\left\{[R_m^2 + 4D^2]^{1/2} - R_m\right\} = \frac{m\lambda}{\sqrt{ke}} \tag{18}$$

where m = 1, 2, 3

Similarly, condition for minima ranges will be:

$$[(R_n^2+4D^2)^{1/2} - R_n] = \frac{(2n+1)\lambda}{2\sqrt{ke}} \tag{19}$$

where n = 0, 1, 2

Furthermore, the ranges of crossover points are given as:

$$[(R_k^2+4D^2)^{1/2} - R_k] = \frac{(2k+1)\lambda}{4\sqrt{ke}} \tag{20}$$

1.3.3 Term $\frac{2y}{RR_3} e^{-\alpha R_3} \cos(\theta_3 - \theta_1)$

This term originates due to interference between free space wave and reflected subsurface wave. Similarly, derived conditions for this case given as below:

For maxima ranges:

$$\left\{\sqrt{ke}\ (R_m^{\ 2} + 4D^2)^{1/2} - R_m\right\} = m\lambda \tag{21}$$

For minima ranges:

$$\left\{\sqrt{ke}\ (R_n^{\ 2} + 4D^2)^{1/2} - R_n\right\} = (2n+1)\frac{\lambda}{2} \tag{22}$$

For crossover points:

$$\left\{\sqrt{ke}\ (R_k^{\ 2} + 4D^2)^{1/2} - R_k\right\} = (2k+1)\frac{\lambda}{4} \tag{23}$$

1.4 Special Cases

Various interference pattern cases of interest can be discussed from the general equation (10) for different values of parameters such as range R, depth D, and reflection coefficient Γ of the reflecting layer, dielectric constant ke, loss tangent $\tan\delta$ of medium, excitation frequency f, etc. Relative amplitude of terms in (10) is an important indicator of contribution by each term and this factor guides the selection of terms in the various cases of interest.

1.4.1 Case: Deeper Discontinuity Layer; Observation Range Not Far from Transmitter

For such a case, $D >> R$; $R \geq \lambda$ and

$$R_3 = D\left[1 + \frac{1}{2}\frac{R^2}{D^2}\right]^{1/2} \simeq D.$$

Since $R_3 >> R$, it follows that in (10) the terms containing R_3 in denominator and in exponential can be neglected because the relative amplitudes contributions are negligible.

Therefore, Equation (10) reduces to the form:

$$|E_T^N| = \left[\frac{1}{R^2} + \frac{e^{-2\alpha R}}{R^2} + \frac{2e^{-\alpha R}}{R^2} \cos\ (\theta_2 - \theta_1)\right]^{1/2} \tag{24}$$

The plots of (24) are drawn in Figures (2) and (3) for the cases ke = 9, tanδ = .0115 and ke = 9, tanδ = .037. It can be seen that location;(ranges) of maxima and minima agree with Equations (12) and (14). Furthermore, for a lossy medium, the location of maxima and minima points remain the same; however, the amplitude excursions get damped due to loss tangent of the medium.

1.4.2 Lossless Deep Dielectric Medium

For such a case, α=0 and Equation (24) takes the form

$$|E_T^N| = \frac{2}{R} \cos\ \left(\frac{\theta_2 - \theta_1}{2}\right) \tag{25}$$

The plots of (25) are shown in Figure 4. It can be seen that maxima and minima locations still remain the same; however, the monotonically decreasing effect is absent. The overall implications are that dielectric constant information can always be derived by noting the spacing of the first few maximas or minimas of the pattern.

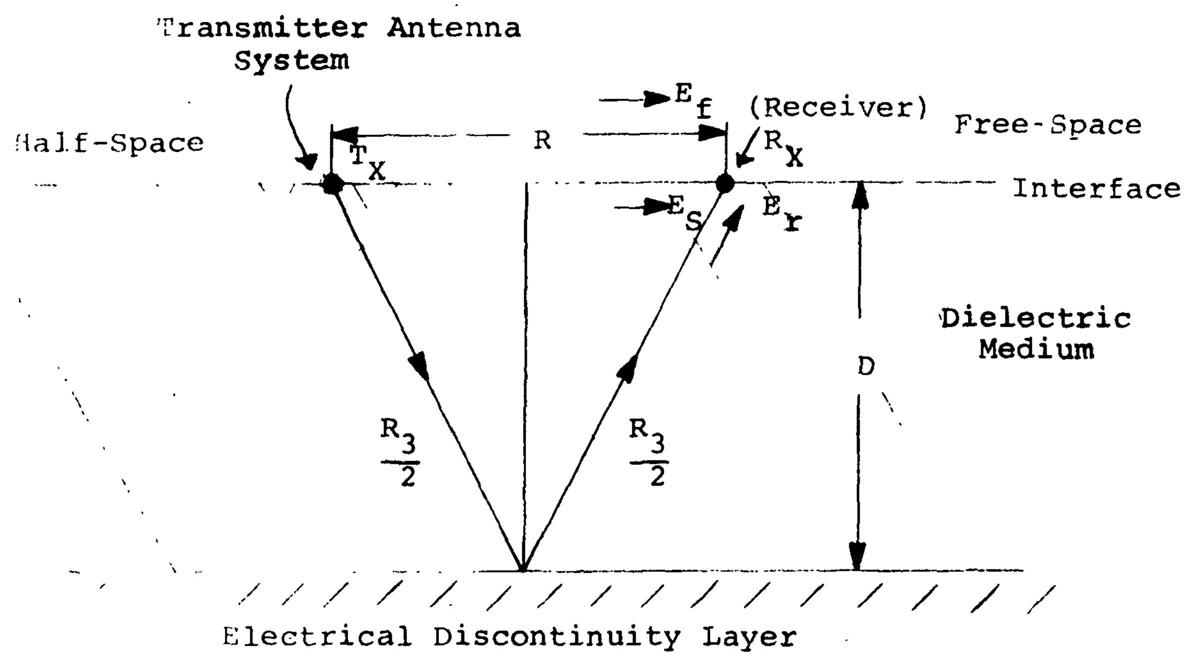


Figure 1. Three Modes of Propagation of R.F. Power from Transmitter to Receiver

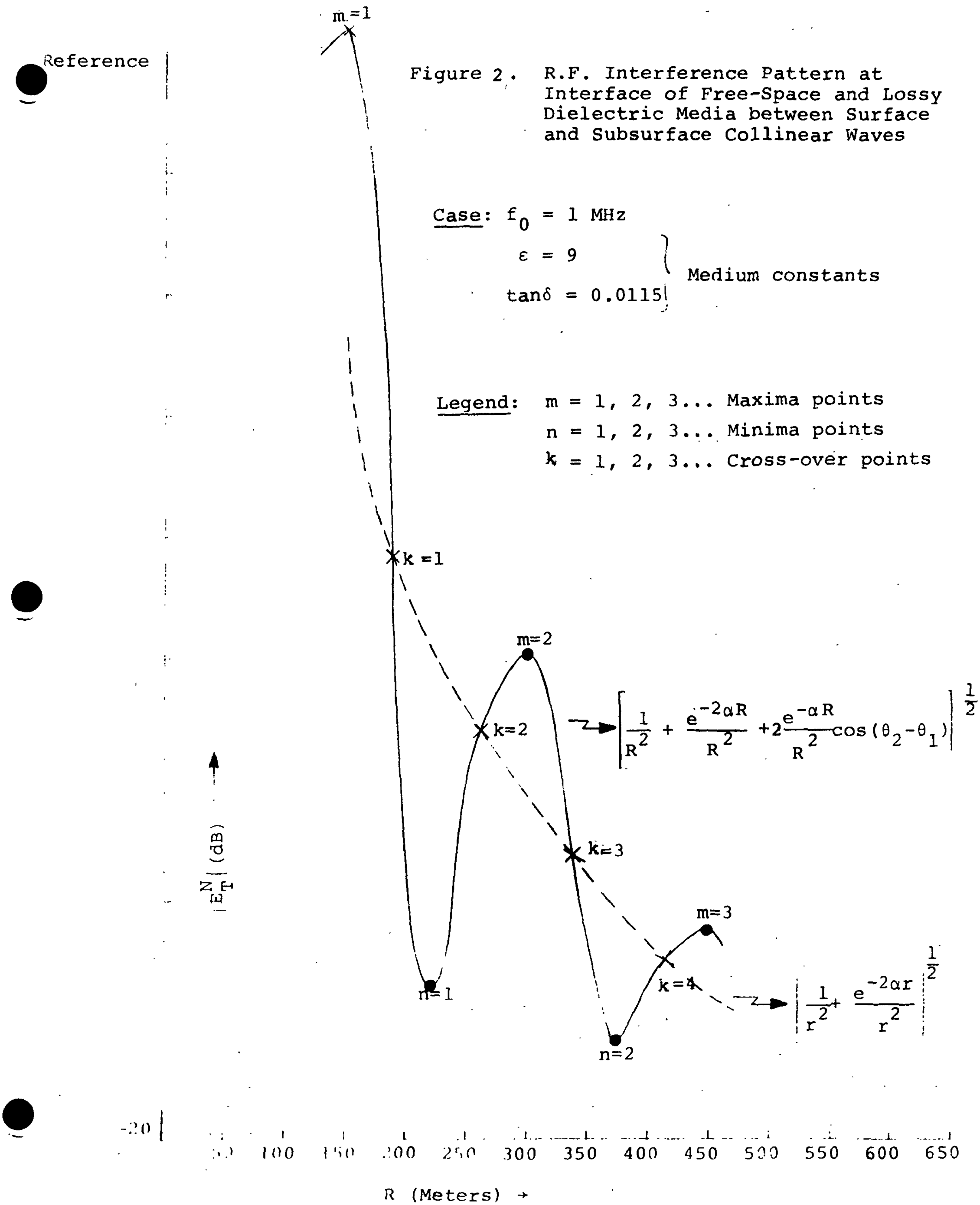


Figure 2. R.F. Interference Pattern at Interface of Free-Space and Lossy Dielectric Media between Surface and Subsurface Collinear Waves

Figure 3. R.F. Interference - Pattern between Free-Space Wave and Collinear Subsurface Wave at the Interface of Free-Space and Lossy Dielectric Medium.

for: $f_0 = 1$ MHz

$\left.\begin{array}{r} \varepsilon = 9 \\ \tan\delta = 0.037 \end{array}\right\}$ Medium Constants

Legend: m = 1, 2, 3,...are maxima points

n = 1, 2, 3,...are minima points

k = 1, 2, 3,...are cross-over points

Reference

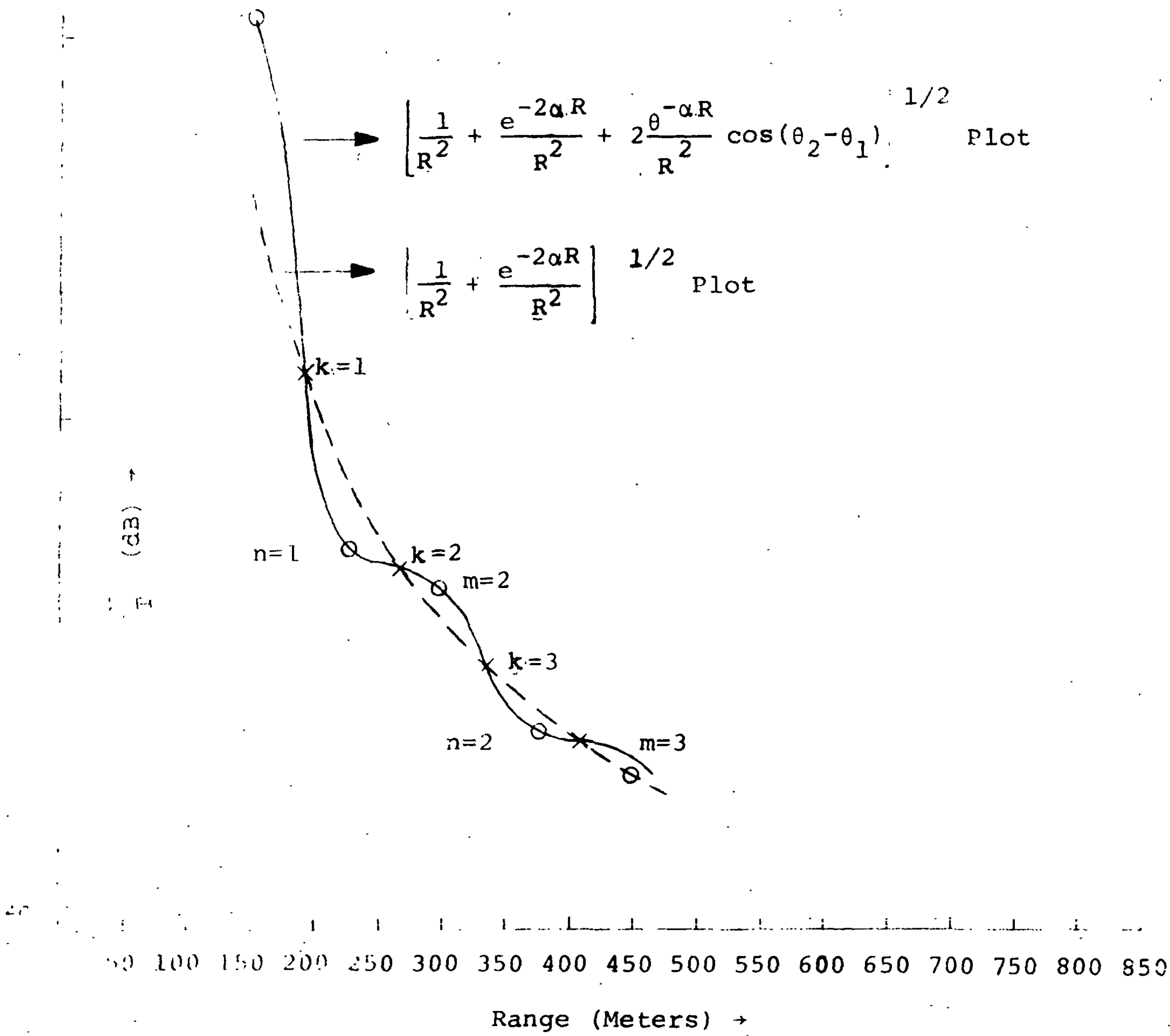
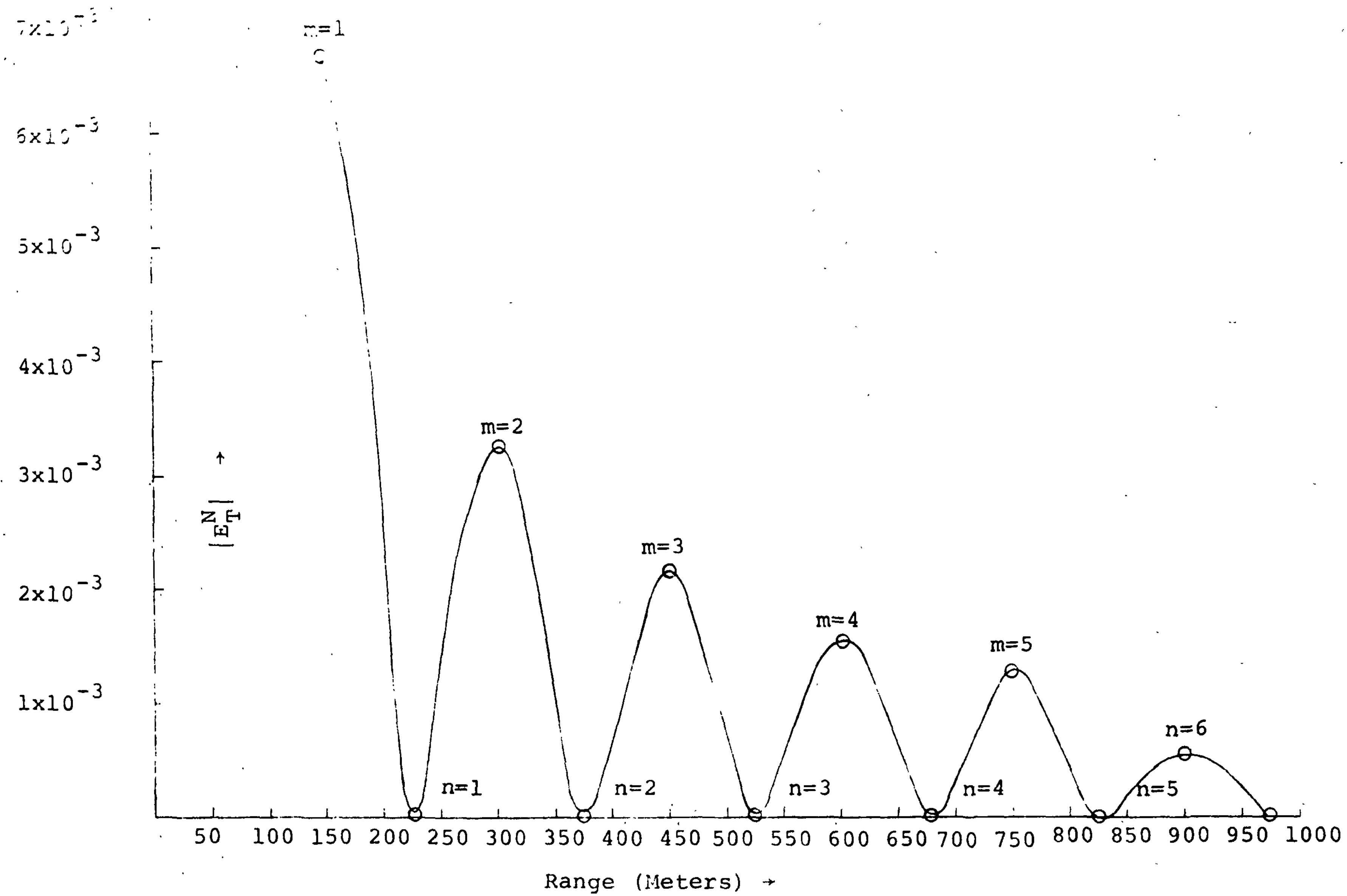


Figure 4. Interference Pattern at the Free-Space - Dielectric Interface @ 1 MHz Lossless Dielectric Medium of $\varepsilon=9$



MEMO NO. VI

DESIGN OF MULTIFREQUENCY LINEAR ANTENNA SYSTEM FOR SEP EXPERIMENT USING INSERTED-FILTER APPROACH

I.1 GENERAL

The proposed antenna system design, shown in Figure 1 (also Table 1), is capable of operating at discrete frequencies in the range 32 MHz to 0.5 MHz with reduced near-field coupling effects. The radiation efficiency at 32 MHz comes about 87% and at 0.5 MHz about 34.6%. Maximum physical length of the antenna system (thin, hollow, extendable) is about 133 meters which can be further reduced at the cost of lowering the radiation efficiency at 0.5 MHz. Furthermore, no high value r.f. currents flow thru antenna structure; therefore no breakdown voltage problem exists across the circuit inductances.

To decrease the near field coupling effects between the successive antenna segments, the criteria for choosing physical length of each segment is,

$$\ell_f/\lambda_f \leq 0.25 \qquad (1)$$

Where:

ℓ_f = total physical length of each dipole

λ_f = excitation wavelength

With this choice of ℓ_f, a good level of radiation efficiency is maintained which can be further augmented by using larger diameter radiating sections, high Q-coil and optimized filter configurations. It is feasible to use strip configuration conductors (thickness << width) as radiating elements.

Lumped circuit elements F_1 through F_6 (refer to Figure 1 and Table 1) are the band stop filters which serve the dual role of selectively exciting the radiating sections and also functioning as tuning impedences. Inductance L_{T32} is primarily a tuning element for the 32 MHz dipole antenna.

I.2 DESIGN COMPUTATIONS

The values of all elements shown in Figure 1 are obtained by the procedures discussed below for a multifrequency, good radiation efficiency antenna systems with reduced near field coupling effects. All computations are based on unloaded radiating elements. The Q-factor of inductance coils is taken to be 300 and that capacitor losses are assumed nominal.

I.2-1 DRIVING-POINT IMPEDANCE FORMULATION

Driving point Impedance Z_D of antenna can be expressed as

$$Z_D = R_o + Z_s \pm Z_m = R_o + (R_{rs} \pm j\, X_s) \pm Z_m \qquad (2)$$

Where:

R_o = Ohmic losses of antenna

Z_s = Self-impedance = $R_{rs} \pm j\, X_s$

R_{rs} = Radiation resistance = Real part of self impedance

X_s = Imaginary part of self impedance

Z_m = impedance due to coupling effects

Values of various terms in equation (2) depend on physical parameters such as antenna length (ℓ), diameter (d), excitation wavelength (λ), characteristics of the medium, etc. A few pertinent equations used for calculating the self impedance of small dipoles are mentioned here:

For a short dipole $\beta\ell/_2 \leq 0.5$;

$$R_{rs} \simeq \frac{\eta}{6\pi}\left(\frac{\beta\ell}{2}\right)^2 \left[\frac{1 + 4\ell n2/\Omega-2}{1 + \frac{2\ell n2}{\Omega-2}}\right]^2 \quad (3)$$

$$X_s \simeq -j\frac{\eta}{\pi\frac{\beta\ell}{2}}\left[\frac{\Omega-2}{1 + \frac{2\ell n2}{\Omega-2}}\right] \quad (4)$$

Where

$\beta = \frac{2\pi}{\lambda}$ = Phase Constant

ℓ = Total length of dipole antenna

Ω = Form Factor of Antenna = $4.6 \log \frac{\ell}{r}$ (5)

r = Radius of Antenna

η = Free Space Impedance = 377Ω

Equations (3) and (4) get simplified for specific values of Antenna Form factor (Ω) and electrical length ranges ($\beta\ell$), giving approximately accurate results; some of these equations are:

for $\Omega = 10,\ \beta\frac{\ell}{2} \leq 1$

$$R_{rs} \simeq 4.58\ \beta^2\ell^2 \left[1 + 0.0215\ \beta^2\ell^2\right] \quad (6)$$

$$X_s \simeq -\frac{792}{\beta\ell}\left[1 - 0.095\ \beta^2\ell^2\right] \quad (7)$$

for $\Omega > 10,\ \beta\frac{\ell}{2} \leq 0.5$

$$R_{rs} \simeq 5\beta^2\ell^2 \left[1 + 0.033\ \beta^2\ell^2\right] \quad (8)$$

$$X_s \simeq -\frac{120}{\beta\ell}\left[\Omega - 3.39\right] \quad (9)$$

The ohmic resistance (R_o) of antenna copper wire is given by

$$R_o = 3.27 \times 10^{-6}\ \frac{\sqrt{f}}{d}\ \text{ohms/meter} \quad (10)$$

Where

f = frequency in hertz

d = diameter of wire in inches

I.2-2 <u>32 MHz Dipole Antenna</u> (ℓ_{32}) <u>Parameters</u>

Segment $\ell_{32}/2$ is the half section of 32 MHz radiating dipole. The length ℓ_{32} of dipole, for reducing the near field coupling effects and making allowance for 10 per cent loading due to glacier proximity, is chosen as

$$\ell_{32} = 0.222 \times \lambda_{32} = 2.08 \text{ meters} \tag{11}$$

For very thin, hollow, telescoping copper tubing of about one inch diameter, the form factor Ω_{32} of the dipole is

$$\Omega_{32} = 4.6 \log \frac{2.08 \times 3.28 \times 12}{0.5} \simeq 10.2 \tag{12}$$

For $\Omega_{32} = 10.2$, radiation resistance and reactance values are:

$$R_{rs} \simeq 10.3\ \Omega \tag{13}$$

$$X_s \simeq -j\ 464 \tag{14}$$

Ohmic resistance $R_o \simeq 3.27 \times 10^{-6} \times \frac{32 \times 10^5}{1} \times 1.04 = 0.02\ \Omega$ (15)

For $\frac{|X_s|}{2} = 232\Omega$, dipole tuning inductance L_{T32} at 32 MHz will be:

$$L_{T32} = \frac{232}{6.28 \times 32 \times 10^{-6}} \simeq 1.15\ \mu H \tag{16}$$

Typically for a Q-value of 300 of coil, the equivalent loss resistance of coil (R_c) will approximately be

$$R_c = \frac{232}{300} \simeq 0.77 \text{ ohm} \tag{17}$$

Total effective ohmic resistance (R_T) of ℓ_{32} dipole =

$$2\left[0.77 + 0.02\right] = 1.58 \text{ ohm} \tag{18}$$

$$\text{Radiation efficiency } (\eta_{32}) \text{ of dipole} = \frac{R_{rs}}{R_{rs} + R_T} \times 100$$

$$= \frac{10.3}{10.3 + 1.58} \times 100 \simeq 87\% \tag{19}$$

I.2-3 Band Stop Filter (F_1) @ 32 MHz

Band stop filter (F_1) highly attennates frequencies around 32 MHz center design frequency and also act as tuning element at the lower frequencies. It is basically a parallel resonance LCR circuit. The circuit element values are computed by the following considerations.

The imaginary part of the tuning impedance of filter F_1 (Z_{F_1} @ 16 MHz) is given by the condition:

$$\text{Im } Z_{F_1} \text{ @ 16 MHz} = j\,282 - \text{Im } Z_{LT_{32}} \text{ @ 16 MHz} \tag{20}$$

$$\text{Im } Z_{LT_{32}} \text{ @ 16 MHz} = j\frac{232}{2} = j\,116\ \Omega$$

$$\text{Im } Z_{F_1} \text{ @ 32 MHz} = j\,166 \times 1.5 = 249\ \Omega \tag{21}$$

$$\text{From (21), inductance } L_{F_{32}} = \frac{249}{6.28 \times 32 \times 10^5} \simeq 1.24\ \mu H \tag{22}$$

$$\text{Capacity } C_{F_{32}} = \frac{1}{4\pi^2 \times (32 \times 10^5)^2 \times 1.24} \simeq 20.2\ pf \tag{23}$$

For $Q \simeq 300$, equivalent resistance of $L_{F_{32}}$ coil $= \frac{249}{300} \simeq 0.83\ \Omega$

$$\frac{L}{C} \text{ ratio} = \frac{1.24 \times 10^{-6}}{20.2 \times 10^{-12}} = 6.14 \times 10^4 \tag{24}$$

It is assumed that capacitor losses are small.

I.2-4 <u>16 MHz Dipole - Antenna (ℓ_{16}) Parameters</u>

Physical length (ℓ_{16}) for 16 MHz dipole antenna will be, ℓ_{16} = .222 X 18.75 ≈ 4.16 meters (25)

This implies that inserting additional wire-section 1.04 meters long (Figure 1) on both sides, ℓ_{16} dipole will be constituted. The electrical parameters of this dipole are computed below.

Form factor Ω_{16} of antenna ≈ 11.6 (26)

Self impedance $Z_s = 10.3 - j564\ \Omega$ (27)

Ohmic resistance $R_o = .055\ \Omega$ (28)

For half-section of ℓ_{16} antenna, total impedance $Z_{T_{16}}$ is given as,

$$Z_{T_{16}} = \frac{Z_S}{2} + \underset{@\ 16\ \text{MHz}}{Z_{LT_{32}}} + \underset{@\ 16\ \text{MHz}}{Z_{F_1}} + \frac{R_o}{2} \qquad (29)$$

For evaluating Z_{F_1} @ 16 MHz, the general expression of band stop filter impedance is:

$$Z_{BSF} = \frac{R\,|X_C|^2 - j\left[\frac{L}{C}(|X_L| - |X_C|) + R^2|X_C|\right]}{R^2 + \left[|X_L| - |X_C|\right]^2} \qquad (30)$$

For

f = 16 MHz case,

$|X_L| = \frac{249}{2} \approx 125\ \Omega$

$|X_C| = 498\ \Omega$

$|X_L| - |X_C| = -373\ \Omega$

$R = \frac{125}{200} = 0.63\ \Omega$

$\frac{L}{C} = 6.14 \times 10^4\ \Omega$

Substituting these values in (30)

$$Z_{F_1 @ 16\ MHz} = 1.49 + j\ 164.2\ \Omega \tag{31}$$

Furthermore, $Z_{LT32 @ 16\ MHz} = 0.77 + j\ 116\ \Omega$ (32)

From (29), (30), (31) and (32), the total impedance Z_T of half section antenna will be,

$$Z_{T_{16}} = \left[\ 5.15 - j\ 282 \right] + (.77 + j\ 116) + (1.49 + j\ 164.2) + .0275$$

$$Z_{T_{16}} \approx 7.44\,\Omega \tag{33}$$

Equation (33) implies that antenna ℓ_{16} is tuned out with proper choice of filter F_1 parameters:

Radiation efficiency η_{16} of this dipole is $= \frac{5.15}{7.44} \times 100 \approx 68.3\%$ (34)

I.2-5 <u>Band-Pass Filter (F_2) @ 16 MHz</u>

The imaginary part of tuning impedance of filter F_2, $Im(Z_{F_2}$ @ 8 MHz), is governed by the condition:

$$Im\ Z_{F_2 @ 8\ MHz} = j\ 333 - \left[Im\ Z_{LT32 @ 8\ MHz} + Z_{F_1 @ 8\ MHz} \right] \tag{35}$$

$$\mathrm{Im}\begin{bmatrix} Z_{LT32} \\ @\ 8\ \mathrm{MHz} \end{bmatrix} = j\frac{116}{2} \approx 58\Omega$$

$$\mathrm{Im}\begin{bmatrix} Z_{F_1} \\ @\ 8\ \mathrm{MHz} \end{bmatrix} \approx \frac{249}{4} \approx 6.2\Omega$$

$$\mathrm{Im}\begin{bmatrix} Z_{F_2} \\ @\ 8\ \mathrm{MHz} \end{bmatrix} = j\ 213\Omega$$

$$\mathrm{Im}\begin{bmatrix} Z_{F_2} \\ @16\ \mathrm{MHz} \end{bmatrix} = j\ 213 \times 1.5 = j\ 319.5\Omega \qquad (36)$$

From (36), inductance $L_{F_{16}} = \dfrac{319.5}{6.28 \times 16 \times 10^6} = 3.18\ \mu H$ (37)

Lossless Capacitance, $C_{F_{16}} = \dfrac{1}{4 \times 9.87 \times (16\times10^6)^2 \times 3.18\times10^{-6}} \approx 31.1\mathrm{pF}$ (38)

$$\frac{L}{C} = \frac{3.18 \times 10^{-6}}{31.1 \times 10^{-12}} = 10.2 \times 10^4 \qquad (39)$$

Equivalent Resistance of filter $= \dfrac{320}{300} = 1.06\ \Omega$

Thus B.S.filter (F_2) elements @ 16 MHz are determined;

(i.e. $L_{F_{16}} = 3.18\ \mu H$; $C_{F_{16}} = 31.1$ pF; $R = 1.06\ \Omega$).

I.2-6 8 MHz Dipole - Antenna(ℓ_8)Parameters

The physical length (ℓ_8) for 8 Mhz dipole antenna is;

$\ell_8 = 0.222 \times 37.50 = 8.32$ meters (40)

Other parameters include:

$\Delta\ell$, additional wire-section to be inserted on both sides = 2.08 meters (41)

Form factor $\Omega_8 \approx 13$ (42)

Self impedance $Z_S \approx 10.3 - j\ 666\ \Omega$ (43)

Ohmic resistance $R_o \approx 2.37 \times 10^{-3} \times \sqrt{8} \times 8.32 \approx .08\Omega$ (44)

Half-section total impedance Z_{T_8} is given as;

$$Z_{T_8} = \frac{Z_s}{2} + \underset{@\ 8\ MHz}{Z_{LT32}} + \underset{@\ 8\ MHz}{Z_{F_1}} + \underset{@\ 8\ MHz}{Z_{F_2}} + \frac{R_o}{2} \quad (45)$$

$$\underset{@\ 8\ MHz}{Z_{LT32}} = 0.77 + j\ 58\ \Omega$$

$$Z_{F_1} @\ 8\ MHz = \frac{0.83 \times 10^6 + j\ [6.14 \times 10^4 \times 9.36]}{8.76 \times 10^5} \simeq 0.9 + j\ 62\,\Omega$$

$$Z_{F_2} @\ 8\ MHz \simeq \frac{1.06 \times 4.1 \times 10^5}{2.3 \times 10^5} + \frac{j\ [10.2 \times 10^4 \times 480]}{489^2} \simeq 1.89 + j\ 213\,\Omega$$

$$Z_{T_8} = (5.15 - j333) + (0.77 + j58) + 0.9 + j62) + (1.89 + j213) + .04$$

$$\simeq 8.75\,\Omega \quad (46)$$

Therefore the dipole is practically tuned out with the preceding lumped networks. The radiation efficiency η_8 of the dipole will be,

$$\eta_8 = \frac{5.15}{8.75} \times 100 \simeq 59\% \quad (47)$$

I.2-7 Band-Stop Filter (F_3) @ 8 MHz

The imaginary part of tuning impedance of filter F_3, Im (Z_{F_3} @ 4 MHz) is given by,

$$Im \begin{bmatrix} Z_{F_3} \\ @4\ MHz \end{bmatrix} = j\ 383 - Im\ \underset{@4MHz}{Z_{LT32}} + \underset{@4MHz}{Z_{F_1}} + \underset{@4MHz}{Z_{F_2}} \quad (48)$$

$$Im \begin{bmatrix} Z_{LT32} \\ @4MHz \end{bmatrix} = j\ \frac{58}{2} = j\ 29\,\Omega$$

$$Im \begin{bmatrix} Z_{F_1} \\ @4MHz \end{bmatrix} = j\ \frac{62}{2} = j\ 31\,\Omega$$

$$Im \begin{bmatrix} Z_{F_2} \\ @4MHz \end{bmatrix} = j\ \frac{320}{4} = j\ 80\,\Omega$$

From (47), $\mathrm{Im}\begin{bmatrix} Z_{F_3} \\ @4MHz \end{bmatrix} = j\ 243\,\Omega$

$$\mathrm{Im}\begin{bmatrix} Z_{F_3} \\ @8MHz \end{bmatrix} = j\ 243 \times 1.5 = j\ 364.5\ \Omega \qquad (49)$$

From (48), inductance $L_{F_8} = \dfrac{364.5}{6.28 \times 8 \times 10^6} = 7.26\ \mu H$ (50)

Capacitance $C_{F_{16}} = \dfrac{1}{39.48 \times (8 \times 10^6)^2 \times 7.26 \times 10^{-6}} = 54.5\ pF$ (51)

$$\frac{L}{C} = \frac{7.26 \times 10^{-6}}{545 \times 10^{-12}} = 13.3 \times 10^4$$

Effective resistance (for $Q = 300$) $= \dfrac{364}{300} \simeq 1.21$

Therefore B.S. filter (F_3) elements @ 8 MHz are shown as below;

($L_{F_8} = 7.26\mu H$; $C_{F_{16}} = 54.5$ pF; $R = 1.21\,\Omega$

I.2-8 <u>4 MHz Dipole Antenna (ℓ_4) Parameters</u>

The physical length (ℓ_4) of 4 MHz antenna will be,

$\ell_4 = .222 \times 75 \simeq 16.64$ meters (52)

Other parameters include:

$\Delta\ell$, additional wire-section to be inserted on both sides $\simeq$ 4.16 Meters (53)

Form factor $\Omega_4 \simeq 14.3$ (54)

Self-impedance $Z_s = 10.3 - j\ 766\ \Omega$ (55)

Ohmic resistance $R_o = 6.54 \times 10^{-3} \times 16.64 = 0.108\ \Omega$ (56)

Half-section total impedance Z_{T_4} is given as,

$$Z_{T_4} = \frac{Z_S}{2} + \underset{@4MHz}{Z_{LT32}} + \underset{@4MHz}{Z_{F_1}} + \underset{@4MHz}{Z_{F_2}} + \underset{@4MHz}{Z_{F_3}} + \frac{R_o}{2} \qquad (57)$$

$\underset{@4MHz}{Z_{LT32}} = 0.77 + j\ 29\,\Omega$

$\underset{@4MHz}{Z_{F_1}} = 0.83 + j\ 31\,\Omega$

$$Z_{F_2 \, @4MHz} \simeq 1.20 + j\,80$$

$$Z_{F_3 \, @4MHz} = \frac{1.21 \times 5.18 \times 10^5}{2.99 \times 10^5} - j\,\frac{\left[13.3 \times 10^4 \; (-547)\right]}{(547)^2} = 2.1 + j\,243$$

$$Z_{T_8} = (5.15-j383) + (0.77+j29) + (0.83+j31) + (1.20+j80) + (2.1+j243) + .05 = 10.1 \text{ ohms} \quad (58)$$

Thus dipole is tuned out with the proceeding lumped networks.

The radiation efficiency, $\eta_4 = \dfrac{5.15}{10.1} \times 100 \simeq 51\%$ (59)

I.2-9 <u>Band-Stop Filter (F_4) @ 4MHz</u>

The imaginary part of tuning impedance of filter F_4 is,

$$\text{Im}\begin{bmatrix} Z_{F_4} \\ @2MHz \end{bmatrix} = j430 - \text{Im}\begin{bmatrix} Z_{LT32} + Z_{F_1} + Z_{F_2} + Z_{F_3} \\ @2MHz \quad @2MHz \quad @\,2MHz \quad @2MHz \end{bmatrix} \quad (60)$$

where;

$$\begin{bmatrix} Z_{LT32} \\ @2MHz \end{bmatrix} = 0.77 + j\frac{29}{2} = 0.77 + j14.5\ \Omega \quad (61)$$

$$\begin{bmatrix} Z_{F_1} \\ @2MHz \end{bmatrix} = 0.83 + j15.5\ \Omega \quad (62)$$

$$\begin{bmatrix} Z_{F_2} \\ @2MHz \end{bmatrix} = 1.06 + j40\ \Omega \quad (63)$$

$$\begin{bmatrix} Z_{F_3} \\ @2MHz \end{bmatrix} = 1.33 + j91\ \Omega \quad (64)$$

From (60), (61), (62), (63), (64);

$$\text{Im}\begin{bmatrix} Z_{F_4} \\ @2MHz \end{bmatrix} = j269\ \Omega \quad (65)$$

$$\text{Im}\begin{bmatrix} Z_{F_4} \\ @4MHz \end{bmatrix} = j269 \times 1.5 = j403.5\ \Omega \quad (66)$$

From 66, Inductance $L_{F_4} = \frac{403.5}{6.28 \times 4 \times 10^6} = 16\ \mu H$ (67)

Capacitance $C_{F_4} = \frac{1}{39.48 \times (4 \times 10^6)^2 \times 16 \times 10^{-6}} = 99.3 pF$ (68)

$\frac{L}{C} = \frac{16 \times 10^6}{99.3} = 1.61 \times 10^5$ (69)

Equivalent resistance $= \frac{403.5}{300} = 1.34\ \Omega$

Thus B.S. filter (F_3) elements @ 4MHz are as below;

(L_{F_4}=16 μH; C_{F_4}=99.3 pF; R = 1.35 Ω)

I.2-10 <u>2MHz Dipole Antenna (ℓ_2) Parameters</u>

The physical length (ℓ_2) of 2MHz antenna will be,

$\ell_2 = 0.222 \times 150 = 33.3$ meters (70)

other antenna parameters include $\Delta\ell$, additional wire-section to be inserted on both sides = 8.32 meters

Form factor, $\Omega_2 = 15.7$ (71)

Self-impedance $Z_s = 10.3 - j860\ \Omega$ (72)

Ohmic resistance $R_o = 3.27 \times 10^{-3} \times \sqrt{2} \times 33.3 = 154 \times 10^{-3} = .154\,\Omega$ (73)

Half-section total impedance Z_{T_2} is given as,

$$Z_{T_2} = \frac{Z_s}{2} + \underset{@2MHz}{Z_{LT32}} + \underset{@2MHz}{Z_{F_1}} + \underset{@2MHz}{Z_{F_2}} + \underset{@2MHz}{Z_{F_3}} + \underset{@2MHz}{Z_{F_4}} + R_o \quad (74)$$

Where:

Z_{LT32} @ 2MHz = 0.77 + j14.5 Ω

Z_{F_1} @ 2MHz = 0.83 + j15.5 Ω

Z_{F_2} @ 2MHz = 1.06 + j40 Ω

Z_{F_3} @ 2MHz = 1.21 + j91 Ω

Z_{F_4} @ 2MHz = 2.68 + j269 Ω

Substituting impedance values in (74);

$$Z_{T_2} = (5.5-j430) + (0.77+j14.5) + (0.83+j15.5) + (1.06+j40) + (1.21+j91) + (2.68+j269) + .072 \simeq 6.62 + j5.5 \ \Omega$$

Therefore dipole is tuned out with preceeding lumped networks.

$$\text{Radiation efficiency } \eta_2 = \frac{5.15}{11.77} \text{ X } 100 \simeq 43.8\% \qquad (76)$$

I.2-11 <u>Band-Stop Filter (F_5) @ 2MHz</u>

The imaginary part of tuning impedance of filter F_5 is,

$$\text{Im}\begin{bmatrix} Z_{F_5} \\ @1MHz \end{bmatrix} = j480 - \text{Im}\Big[\underset{@1MHz}{Z_{LT32}} + \underset{@1MHz}{Z_{F_1}} + \underset{@1MHz}{Z_{F_2}} + \underset{@1MHz}{Z_{F_3}} + \underset{@1MHz}{Z_{F_4}}\Big] \qquad (77)$$

where:

$$Z_{LT32} \text{ @ 1MHz} = 0.77 + j\frac{232}{32} = 0.77 + j7.5 \ \Omega \qquad (78)$$

$$Z_{F_1} \text{ @ 1MHz} = 0.83 + j\frac{249}{32} = 0.83 + j7.74 \ \Omega \qquad (79)$$

$$Z_{F_2} \text{ @ 1MHz} = 1.02 + j\frac{319.5}{16} = 1.02 + j20.0 \ \Omega \qquad (80)$$

$$Z_{F_3} \text{ @ 1MHz} = 1.21 + j\frac{364.5}{8} = 1.21 + j45.5 \ \Omega \qquad (81)$$

$$Z_{F_4} \text{ @ 1MHz} = 1.47 + j\frac{403.5}{4} = 1.47 + j100.875 \ \Omega \qquad (82)$$

From (77) to (82):

$$\text{Im}\Big[Z_{F_5} \text{ @ 1MHz}\Big] = j298 \ \Omega$$

$$\text{Im}\Big[Z_{F_5} \text{ @ 2MHz}\Big] = .5 = j477 \ \Omega \qquad (83)$$

$$\text{From (83), inductance } L_{F_5} = \frac{447}{6.28X2X10^6} = 35.6\mu H \qquad (84)$$

$$\text{capacitance } C_{F_5} = \frac{1}{39.48X(2X10^6)^2X35.6X10^{-6}} = 178pF \qquad (85)$$

$$\frac{L}{C} = \frac{35.6X10^6}{178} = 2X10^5 \qquad (86)$$

$$\text{Equivalent Resistance (R)} = \frac{447}{300} = 1.49 \ \Omega \qquad (87)$$

Thus B.S. filter (F_5) elements @ 2MHz are the following:

$L_{F_5} = 35.6\ \mu H$, $C_{F_5} = 178$ pF, $R = 1.49\ \Omega$

I.2.12 1MHz Dipole Antenna (ℓ_1) Parameters

The physical length (ℓ_1) of 1MHz antenna will be,

$$\ell_1 = 0.222 \times 300 = 66.6 \text{ meters} \tag{88}$$

Other antenna parameters include;

$\Delta\ell$, additional wire-section to be inserted on both sides = 16.64 meters

$$\text{Form factor, } \Omega_1 = 17.1 \tag{89}$$

$$\text{Self-impedance } Z_s = 10.3 - j960\,\Omega \tag{90}$$

$$\text{Total Ohmic resistance } (R_o) = 0.218\,\Omega \tag{91}$$

Half-section total impedance Z_{T_1} is given as;

$$Z_{T_1} = \frac{Z_s}{2} + \underset{@1MHz}{Z_{LT32}} + \underset{@1MHz}{Z_{F_1}} + \underset{@1MHz}{Z_{F_2}} + \underset{@1MHz}{Z_{F_3}} + \underset{@1MHz}{Z_{F_4}} + \underset{@1MHz}{Z_{F_5}} + R_o \tag{92}$$

Where:

$$Z_{F_5} = \frac{1.49X8.03X10^5}{4.52X10^5} + j\,\frac{2X10^5}{672} = 2.65 + j\,298\,\Omega$$

$$Z_{T_1} = (5.15-j480) + (0.77+j7.5) + (0.83+j7.74) + (1.06+j20) + (1.21+j45.5) + (1.47+j100.87) + (2.65+j298) \simeq 13.10\,\Omega \tag{93}$$

Therefore, antenna is tuned out with preceeding lumped networks.

$$\text{Radiation efficiency } \eta_1 = \frac{5.15}{13.14} X\ 100 = 39\% \tag{94}$$

I.2-13 Band-Stop Filter (F_6) @ 1MHz

The imaginary part of tuning impedance of filter F_6 is,

$$\mathrm{Im}\left[\underset{@0.5MHz}{Z_{F_6}}\right] = j530 - \mathrm{Im}\left[\underset{@0.5MHz}{Z_{LT32}} + \underset{@0.5MHz}{Z_{F_1}} + \underset{@0.5MHz}{Z_{F_2}} + \underset{@0.5MHz}{Z_{F_3}} + \underset{@0.5MHz}{Z_{F_4}} + \underset{@0.5MHz}{Z_{F_5}}\right] \tag{95}$$

Where:

$$Z_{LT32} @ 0.5MHz - 0.77 + j3.75\,\Omega \tag{96}$$

$$Z_{F_1} @ 0.5MHz = 0.83 + j3.87\,\Omega \tag{97}$$

$$Z_{F_2} \text{ @ } 0.5\text{MHz} = 1.02 + j10\ \Omega \tag{98}$$

$$Z_{F_3} \text{ @ } 0.5\text{MHz} = 1.21 + j23\ \Omega \tag{99}$$

$$Z_{F_4} \text{ @ } 0.5\text{MHz} = 1.34 + j50.4\ \Omega \tag{100}$$

$$Z_{F_5} \text{ @ } 0.5\text{MHz} = 1.64 + j112\ \Omega \tag{101}$$

From (95) to (101),

$$\text{Im}\left[Z_{F_6} \text{ @ } 0.5\text{MHz}\right] = j327\ \Omega$$

$$\text{Im}\left[Z_{F_6} \text{ @ } 1\text{MHz}\right] = j327 \times 1.5 = 490\ \Omega \tag{102}$$

From (102),

$$\text{inductance } L_{F_6} = \frac{490}{6.28 \times 1 \times 10^6} = 78\ \mu\text{H} \tag{103}$$

$$\text{capacitance } C_{F_6} = \frac{1}{39.48\text{X}(1\text{X}10^6)^2\text{X}78\text{X}10^{-6}} = 324\ \text{pF} \tag{104}$$

$$\frac{L}{C} = \frac{78\text{X}10^6}{324} = 2.41\text{X}10^5 \tag{105}$$

$$\text{Effective resistance } (Q \approx 300) = \frac{490}{300} = 1.63\Omega \tag{106}$$

Thus B.S. filter (F_6) elements @ 1MHz are as below;

L_{F_6} =78 μH; C_{F_6} = 324 pF; Q = 300

VI.2-14 <u>0.5 MHz Dipole Antenna ($\ell_{0.5}$) Parameters</u>

The physical length ($\ell_{0.5}$) of 0.5 MHz antenna will be

$$\ell_{0.5} = 0.222 \times 600 = 133.2 \text{ meters} \tag{107}$$

Other antenna parameters include;

$\Delta\ell$, additional wire section to be inserted on both sides = 33.3 meters

Form factor, $\Omega_{0.5} = 18.5$ (108)

Self-impedance $Z_s = 10.3 - j1061\ \Omega$ (109)

Total ohmic resistance $= 0.3\ \Omega$ (110)

Half-section total impedance $Z_{T_{0.5}}$ is given by:

$$Z_{T_{0.5}} = \frac{Z_s}{2} + \underset{@0.5MHz}{Z_{LT32}} + \underset{@0.5MHz}{Z_{F_1}} + \underset{@0.5MHz}{Z_{F_2}} + \underset{@0.5MHz}{Z_{F_3}} + \underset{@0.5MHz}{Z_{F_4}} + \underset{@0.5MHz}{Z_{F_5}} + \underset{@0.5MHz}{Z_{F_6}} + \frac{R_o}{2} \quad (111)$$

Where:

$$\underset{@0.5MHz}{Z_{F_6}} = \frac{1.63X9.6X10^5}{5.4X10^5} + j\,\frac{2.41X10^5}{735} = 2.89 + j328\ \Omega$$

$$Z_{T_{0.5}} = (5.15-j530) + (0.77 + j3.75) + (0.83-j3.87) + (1.06 + j10) + (1.21 + j22.75) + (1.34 + j50.43) + (1.64 + j112) + (2.89 + j328) + 0.15 \simeq 14.89\ \Omega \quad (112)$$

Therefore antenna $\ell_{0.5}$ is tuned out with the proceeding lumped network.

Radiation efficiency $\eta_{0.5} = \frac{5.15}{14.89} X\ 100 \simeq 34.6\%$ (113)

I.3 Concluding Remarks

Preceeding computations demonstrate the feasibility of a transmitting multi-frequency linear antenna system operatable in the frequency range 0.5 to 32 MHz using the inserted-filter approach. Any dielectric loading of antenna due to interface medium will further reduce physical length of the antenna system. If the present proposed antenna system is restricted to a maximum length of 66 meters, the computed radiation efficiencies will still be retained up to 1 MHz;

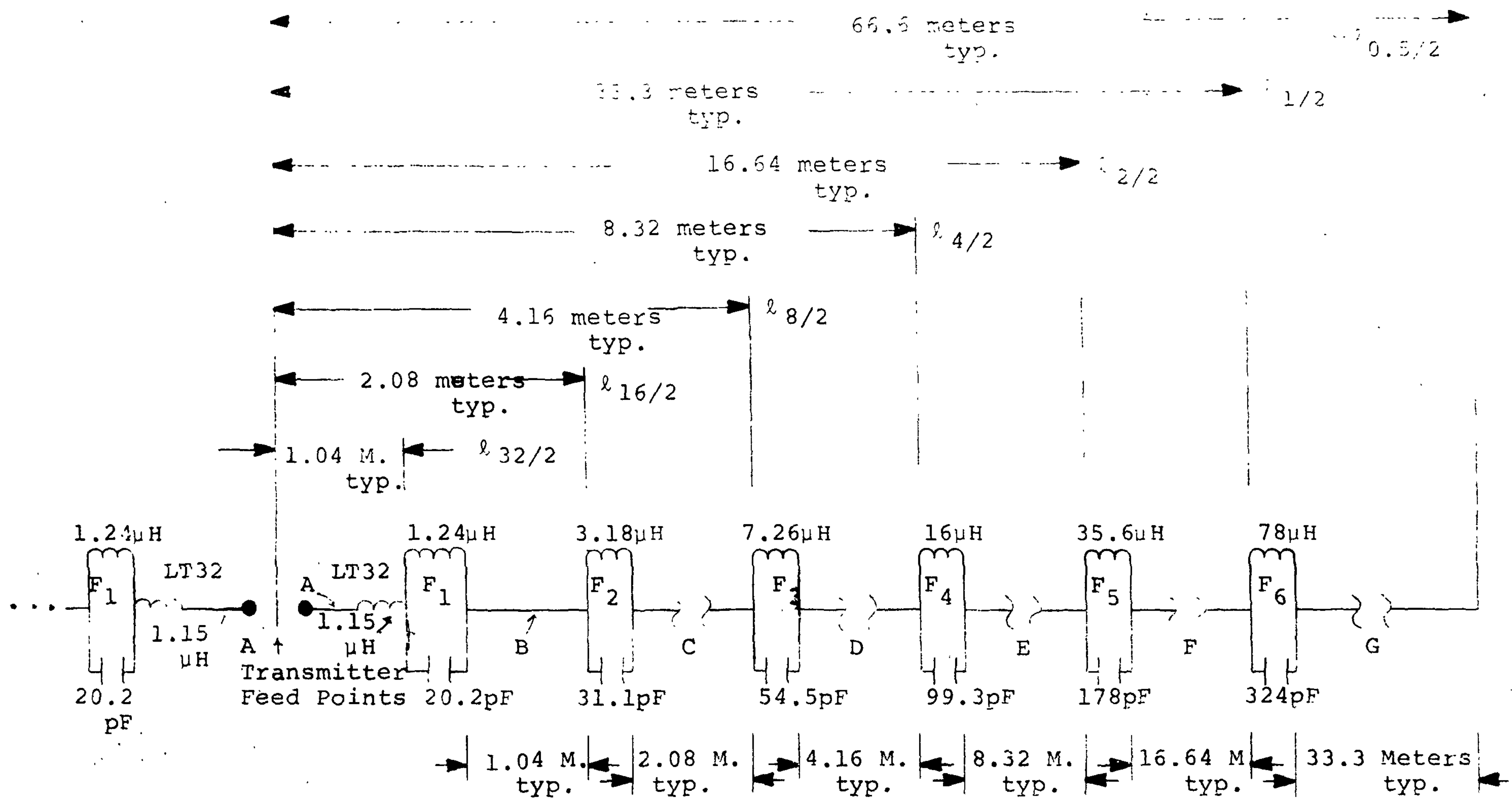
however, for 0.5 MHz, the radiation efficiency may get reduced to about 10 per cent.

To optimize the radiation efficiency of the antenna system, it is suggested to undertake computer analysis especially about the band stop filter configurations. Also, hardware development efforts should be directed in securing the high Q inductance coils; the band stop filter circuits should at least have $Q \geq 300$ over the frequency range of interest.

Table 1 Specifications of Transmitting Antenna-System Elements for the SEP Experiment*

Item Description	Quantity	Frequency Range	Electrical Characteristics	Unfurled Physical Length
A Segment	2	32MHz to 0.5MHz	Radiation efficiency $\eta_{32} = 87\%$	1.04 meters
B Segment	2	16 to 0.5 MHz	$\eta_{16} = 68.3\%$	1.04 meters
C Segment	2	8 to 0.5 MHz	$\eta_{8} = 59\%$	2.08 meters
D Segment	2	4 to 0.5 MHz	$\eta_{4} = 51\%$	4.16 meters
E Segment	2	2 to 0.5 MHz	$\eta_{2} = 43\%$	8.32 meters
F Segment	2	1 to 0.5 MHz	$\eta_{1} = 39\%$	16.64 meters
G Segment	2	0.5 Mhz	$\eta_{0.5} = 34.6\%$	33.3 meters
LT_{32} Tuning Inductance	2	32 to 0.5 MHz	1.15 μH @32 MHz Q ≃ 300 @ 0.5 to 32 MHz	
F_1 Band Stop Filter	2	32 to 0.5 MHz	$f_{B.S.} = 32$ MHz L = 1.24μH Q ≃ 300 C = 20.2pf	
F_2 B.S. Filter	2	16 to 0.5 MHz	$f_{B.S.} = 16$ MHz L = 2.18μH Q ≃ 300 C = 31.1pf	
F_3 B.S. Filter	2	8 to 0.5 MHz	$f_{B.S.} = 8$ MHz L = 7.26μH Q ≃ 300 C = 54.5pf	
F_4 B.S. Filter	2	4 to 0.5 MHz	$f_{B.S.} = 4$ MHz L = 16μH Q ≃ 300 C = 99.3pf	
F_5 B.S. Filter	2	2 to 0.5 MHz	$f_{B.S.} = 2$ MHz L = 35.6μH Q ≃ 300 C = 178pf	
F_6 B.S. Filter	2	1 to 0.5 MHz	$f_{B.S.} = 1$ MHz L = 78μH Q ≃ 300 C = 324pf	

*For additional details: refer to Figure 1 and the main text.



NOTES:
(1) Drawing not to scale.
(2) Filter-section dimensions negligible.
(3) 33.3 meter section can be eliminated with reduction in radiation efficiency @ 0.5 MHz only.
(4) Refer to main-text and Table 1 for additional details.

Figure 1. Multifrequency Linear Antenna System for SEP Experiment (32 MHz to 0.5 MHz)

MEMO NO. VII

STRIP CONFIGURATION ANTENNA FOR SEP EXPERIMENT

I.1. GENERAL

It is proposed to use strip configuration as radiating elements for the SEP transmitter antenna. Such an antenna is characterized by thickness (t) much smaller than width (w) of strip (Refer to Figure 1).

Various advantages of this configuration are enumerated below;

(1) Mechanically ; compact, flat, flexible, etc.

(2) Lesser ohmic loss; therfore, higher radiation efficiency; hence, smaller transmitter power requirements.

(3) Lower magnitude of tuning reactances, thereby minimizing voltage breakdown problem for small electrical length radiating elements.

(4) For glacier-site experiments, no need for any antenna tuning elements at least from 32 MHz to 4 MHz employing the packaging concept shown in Figure 2.

Theoretical justification and design criteria for strip antenna will be discussed and a quantitative comparison made with other antenna configurations.

I.2. ELECTROMAGNETIC EQUIVALENCE OF ARBITRARY CROSS-SECTION ANTENNA TO CIRCULAR CROSS-SECTION ANTENNA

For circular cross-section antenna of length ℓ oriented along the z-axis, the field components determining factor is the magnetic vector potential A_z whose value at distance R is

$$A_z(R) = \frac{\mu}{4\pi} \int_{-\ell/2}^{\ell/2} I(z) \frac{e^{-j\beta R}}{R} dz \qquad (1)$$

Function I(z) in (1) is the current distribution function which implicitly depends on the form factor (Ω) of antenna; in other words, it has dependence on antenna length and its cross-sectional shape and size. For circular cross-sectional antenna, the form factor (Ω) is derived as,

$$\Omega = 2 \ln \frac{\ell}{r} \qquad (2)$$

where:

r = radius of antenna

ℓ = length of antenna

μ = permeability factor

For the case of arbitrary cross-section antenna, it is therefore necessary to determine first the equivalent circular effective radius (r_e) leading to form factor parameter (Ω_e). The general equivalent form factor expression is,

$$\Omega_e \triangleq 2\ln\frac{\ell}{r_e} = 2 \oint_p \frac{1}{f(p)} \ln \frac{\ell}{r_r} dp \qquad (3)$$

where:

Ω_e = general equivalent form factor for arbitrary cross-section antenna

r_e = equivalent effective radius

$f(p)$ = Perimeter function of arbitrary cross-section

r_r = random length on the cross-section of arbitrary cross-section antenna

dp = infinitesimal length along the perimeter of arbitrary cross-section antenna

Applying the effective form-factor concept mentioned above to the specific case of strip antenna, it can be seen from Figure 1 geometry that

$$f(p) = 2(w+t) \approx 2w \tag{4}$$

$$r_r = \frac{w}{2} \cos \phi \tag{5}$$

$$dp = \frac{w}{2} \cos\phi \; d\phi \tag{6}$$

where:

w,t = width and thickness of strip antenna

ϕ = angle which random length r_r makes with the base-line

From (3),(4),(5),and (6)

$$r_e = 0.25\ w \tag{7}$$

Equation (7) is the equivalent radius relationship.

Furthermore, since the excitation wave length is mush greater than the arbitrary cross-section dimensions, the radiation pattern and gain will, therefore, still be like a dipole antenna.

This aspect of transformation to circular cross-section has also been investigated using variational method techniques. The derived expression with the alternative approach is,

$$r_e = \frac{w}{4}\left[1 + \frac{t}{\pi w} \ln\left(4\pi e \frac{w}{t}\right)\right] \tag{8}$$

where: $t \ll w$; $e = 2.718$

Within the first order approximation,(8) agrees with (7). It can be seen that since thickness (t) of the strip makes a very nominal contribution to the equivalent circular radius (r_e); therefore, strip thickness can be chosen as small as possible within the limits of mechanical feasibility and skin-depth requirements of r.f. currents.

I.3. DESIGN PARAMETERS OF STRIP-CONFIGURATION ANTENNA

Having determined the equivalent radius of strip-antenna, the following set of equations lead to the electrical parameters of strip antenna. Form factor (Ω_e) of strip antenna is defined by

$$\Omega_e = 4.6 \log \frac{\ell}{r_e} \tag{9}$$

where: ℓ = total length of strip antenna

r_e = equivalent radius of strip antenna.

The radiation resistance and reactance of short antenna,

$\left(\beta \frac{\ell}{2} \leq 0.5 \atop \Omega > 10 \right)$ is accurately given by;

$$R_{rs} \approx 5\ \beta^2\ \ell^2\ [1 + 0.033\ \beta^2 \ell^2] \tag{10}$$

$$X_S \approx -j\ \frac{120}{\beta\ell}\ (\Omega - 3.39) \tag{11}$$

where:

R_{rs} = radiation resistance of antenna

X_S = reactance of antenna

$\beta \approx \frac{2\pi}{\lambda}$ = Phase constant

However, the more general expressions for radiation resistance and self-reactance of center-fed linear dipole antenna will be:

$$R_{rs} = 60 \left\{ C + \ell n\ \beta\ell - C_i(\beta\ell) + \frac{1}{2} \sin(\beta\ell) \left[S_i(2\beta\ell) - 2S_i(\beta\ell) \right] + \frac{1}{2} \cos(\beta\ell) \left[C + \ell n (\frac{\beta\ell}{2}) + C_i(2\beta\ell) - 2C_i(\beta\ell) \right] \right\} \tag{12}$$

$$X_S = -j \left\{ 120 (\ell n \frac{\ell}{r} - 1)\ \cot \frac{\beta\ell}{2} - 30 \left[2S_i(\beta\ell) + \cos\beta\ell [2S_i(\beta\ell) - S_i(2\beta\ell)] - S_i \beta\ell \left[2C_i(\beta\ell) - C_i(2\beta\ell) - C_i\ \frac{2\beta r^2}{\ell} \right] \right] \right\} \tag{13}$$

where:

r, ℓ = radius and total length of linear dipole antenna

C = Euler's constant, 0.5772

$$S_i(\beta\ell) = \int_0^{\beta\ell} \frac{\sin \beta\ell}{\beta\ell}\, d(\beta\ell) \tag{14}$$

$$C_i(\beta\ell) = -\int_{\beta\ell}^{\infty} \frac{\cos \beta\ell}{\beta\ell}\, d(\beta\ell) \tag{15}$$

The loss resistance R_0 of copper strip antenna is evaluated from the equation:

$$R_0 = 3.27\text{x}10^{-6} \frac{\sqrt{f}}{d_e} \text{ ohms/meter} \tag{16}$$

where:

f = frequency in hertz

d_e = equivalent diameter in inches of strip antenna = $2r_e$

Using the design equations discussed above, the electrical parameters of various linear dipole antennas are tabulated for ready reference and comparison:

Table No.	Antenna Configuration	Length (Meters)	Cross-Section Dimensions	Frequency Range of Operation
I.	Strip	4.69	1.25" x t(small)	32 MHz to 4 MHz
II.	Strip	37.5	1.25" x t(small)	4 MHz to 0.5 MHz
III.	wire #24	4.69	.020"diameter	32 MHz to 4 MHz
IV.	wire #24	37.5	.020"diameter	4 MHz to 0.5 MHz
V.	Tubing	4.69	1.00"diameter	32 MHz to 4 MHz
VI.	Tubing	37.5	1.00"diameter	4 MHz to 0.5 MHz

The computations for the cases tabulated above are based on unloaded antennas using simplified versions of self-impedance formulae (depending on the electrical length $\beta\ell$ and the form factor Ω) and also extrapolations wherever necessary. For rigorous values, computer computations can be made of the general expressions (12) and (13).

Design data in Tables I through VI indicate that strip-configuration antenna has superior electrical parameters along with the advantage of easy mechanical compactness of packaging. The term $\frac{R_{rs}}{R_{rs} + R_0}$ is a measure of radiation efficiency assuming very high Q matching elements are available.

TABLE I

SELF-IMPEDANCE, Q-FACTOR DATA

FOR HARMONIC-INPUT CENTER-FED STRIP-CONFIGURATION, LINEAR ANTENNA

Total length of antenna (ℓ) = 4.69 meter Form Factor (Ω) = 12.74

Cross-Section of antenna = [1.25" x t] width thickness (very small) Antenna Material: Copper (95%) alloy

λ_0 (Excitation Wave Length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohms)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S\rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductance for Half Antenna Section
9.38 Meter (32 MHz)	0.5	82.8 ohm	≃ +j42 ohm	0.138 ohm	82.94	≃0.97	≃0.5	--	--
18.76 " (16 MHz)	0.250	13.6 "	≃ -j538 "	0.0978 "	13.7	≃0.99	39.3	5.3 μH	2.65 μH
37.5 " (8 MHz)	0.125	3.2 "	-j1430 "	.0693 "	3.27	≃0.98	438	28.5 μH	14.25 μH
75 " (4 MHz)	.0625	≃0.8 "	≃ -j2860 "	≃.0492 "	≃ 0.85	≃0.94	3370	114 μH	57 μH

TABLE II

SELF-IMPEDANCE, Q-FACTOR DATA

FOR HARMONIC-INPUT CENTER-FED STRIP-CONFIGURATION, LINEAR ANTENNA

Total length of antenna (ℓ) = 37.5 meters

Form Factor(Ω) = 16.89

Cross-Section of antenna = [1.25" x t] width thickness (very small)

Antenna Material: Copper alloy (95%cu)

λ_0 (Excitation Wave Length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohm)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S\rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductanc for Half Antenna Section
75 Meters (4 MHz)	0.5	≈80 ohm	≈j43 ohm	0.390 ohm	≈80.4	≈0.79	≈0.5	--	--
150 " (2 MHz)	0.25	13.3 "	-j876 "	0.276 "	13.85	≈0.985	64.4	70 μH	35 μH
300 " (1 MHz)	0.125	3.2 "	-j2065"	0.196 "	3.4	≈0.94	605	329 μH	164.5 μH
600 " (o.5 MHz)	0.0625	≈0.8"	-j4130"	0.139 "	0.94	≈0.85	4400	1315 μH	607.5 μH

TABLE III

SELF-IMPEDANCE, Q-FACTOR DATA

FOR HARMONIC-INPUT CENTER-FED WIRE-CONFIGURATION, LINEAR ANTENNA

Total length (ℓ) = 4.69 meters

Form Factor (Ω) = 18.3

Cross-section of antenna = 0.020"diameter #24 wire

Antenna Material: Copper

0 (Excitation Wave Length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohms)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S\rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductance for Half Antenna Section
9.38 Meter (32 MHz)	0.5	≃84 ohm	≃ +j40 ohm	4.31 ohm	88.31	≃0.95	≃0.46	--	--
18.76 " (16 MHz)	0.25	13.6 "	-j965 "	3.06 "	16.66	≃0.816	58	9.6 μH	4.8 μH
37.5 " (8 MHz)	0.125	≃3.2 "	-j2275 "	2.16 "	5.36	≃0.597	424	45.2 μH	22.6μH
75 " (4 MHz)	.0625	≃0.8 "	-j4550 "	1.54 "	2.34 "	≃0.342	1940	181 μH	90.5 μH

TABLE IV

SELF-IMPEDANCE, Q-FACTOR DATA

FOR HARMONIC-INPUT CENTER-FED WIRE-CONFIGURATION, LINEAR ANTENNA

Total length of antenna (ℓ) = 37.5 meters   Form Factor (Ω) = 22.4

Cross-Section of antenna = 0.020 " diameter (#24 wire)   Antenna Material: Copper

λ_0 (Excitation Wave Length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohms)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S \rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductance for Half Antenna Section
75 Meters (4 MHz)	0.5	≈82 ohm	≈j40 ohm	12.2 ohm	94.2	0.87	≈0.43	--	--
150 " (2 MHz)	0.250	13.6 "	≈-j1120 "	8.65 "	22.25	0.61	50.2	89 μH	44.5 μH
300 " (1 MHz)	0.125	3.2 "	-j2900 "	6.14 "	9.34	0.34	311	462 μH	231 μH
600 " (0.5 MHz)	.0625	≈0.8 "	-j5800 "	4.35 "	5.15	0.155	1130	1848 μH	924 μH

TABLE V

SELF-IMPEDANCE, Q-FACTOR DATA

HARMONIC-INPUT, CENTER-FED TUBING-CONFIGURATION, LINEAR ANTENNA

Total length of antenna (ℓ) = 4.69 Meters Form Factor (Ω) = 11.8

Cross-Section of antenna = 1.00" diameter Antenna material: copper

λ_0 (Excitation Wave length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohms)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S\rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductance for Half Antenna Section
9.68 Meter (32 MHz)	0.5	≈83 ohm	+j40 ohm	0.084 ohm	83.08	≈.999	≈0.5	--	--
18.76 " (16 MHz)	0.25	13.6 "	-j520 "	0.06 "	13.66	≈.999	38	5.18 μH	2.59 μH
37.5 " (8 MHz)	0.125	3.2 "	-j1275 "	0.043 "	3.24	≈.99	394	25.4 μH	12.7 μH
75 " (4 MHz)	.0625	≈.8 "	-j2555 "	0.031 "	0.83	≈.965	3080	≈102 μH	51 μH

TABLE VI

SELF-IMPEDANCE, Q-FACTOR DATA

FOR HARMONIC-INPUT, CENTER-FED TUBING-CONFIGURATION, LINEAR ANTENNA

Total length of antenna (ℓ) = 37.5 meters Form Factor (Ω) = 15.5

Cross-Section of antenna = 1.00 " diameter Antenna Material: Copper

λ_0 (Excitation Wave Length)	$\frac{\ell}{\lambda_0}$	R_{r_s} (Radiation Resistance)	X_S (Imaginary Part of Self-Imped.)	R_0 (Ohmic Loss in Antenna Segment)	$R_{r_s}+R_0$ (ohms)	$\frac{R_{r_s}}{R_{r_s}+R_0}$	$Q=\frac{\lvert X_S\rvert}{R_{r_s}+R_0}$	(L) Total Tuning Inductance for Antenna	(L/2) Tuning Inductance for Half Antenna Section
75 Meter (4 MHz)	0.5	≈80.2 ohm	+j43 ohm	0.239 ohm	80.44	≈.999	≈0.5	--	--
150 " (2 MHz)	0.25	13.6 "	-j690 "	0.171 "	13.77	≈.99	50.1	55 μH	27.5 μH
300 " (1 MHz)	0.125	3.2 "	-j1850"	0.122 "	3.32	≈.964	558	294 μH	147 μH
600 " (0.5 MHz)	.0625	≈0.8 "	-j3700"	0.087 "	0.88	≈0.91	4200	1118 μH	559 μH

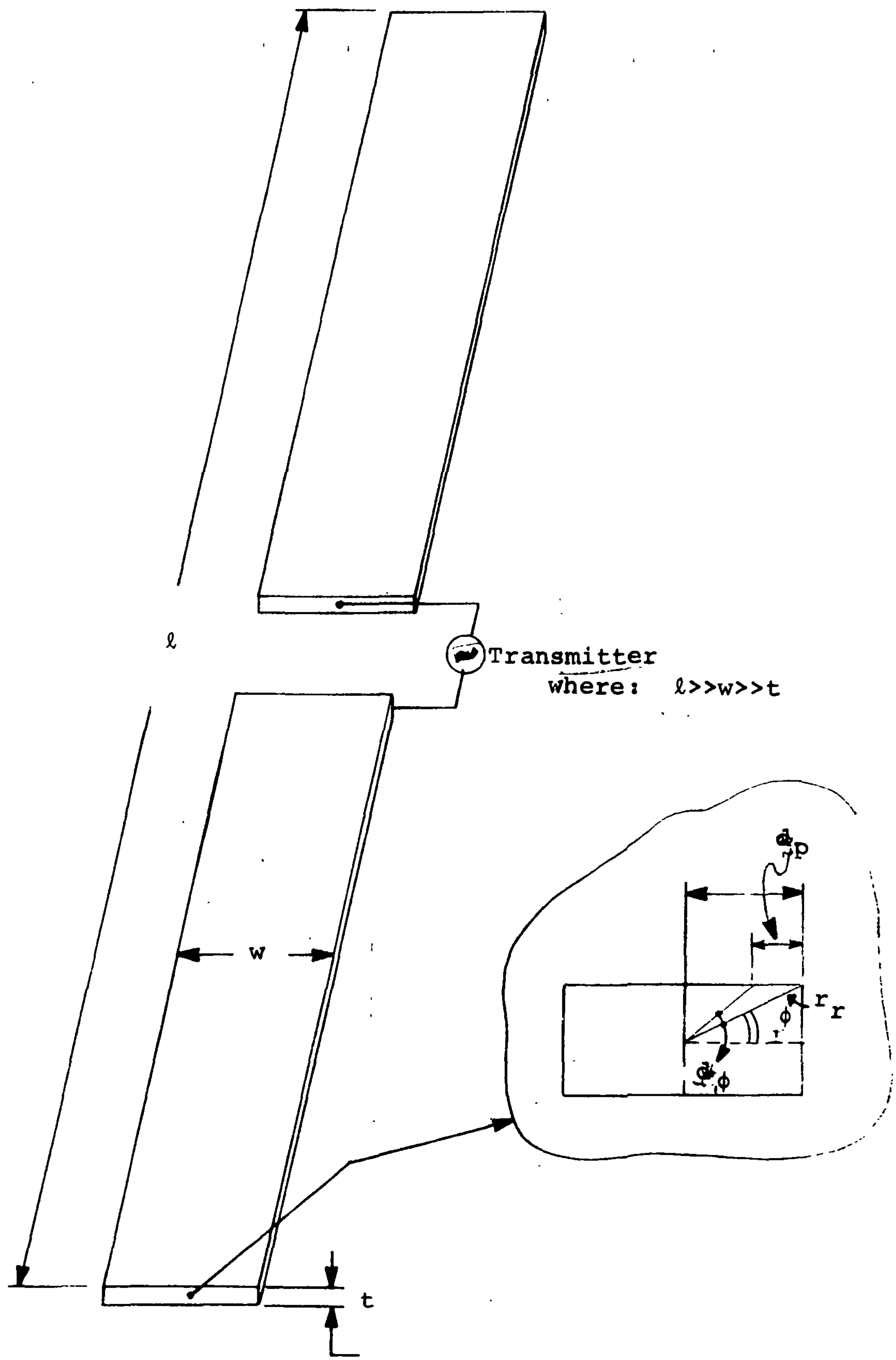
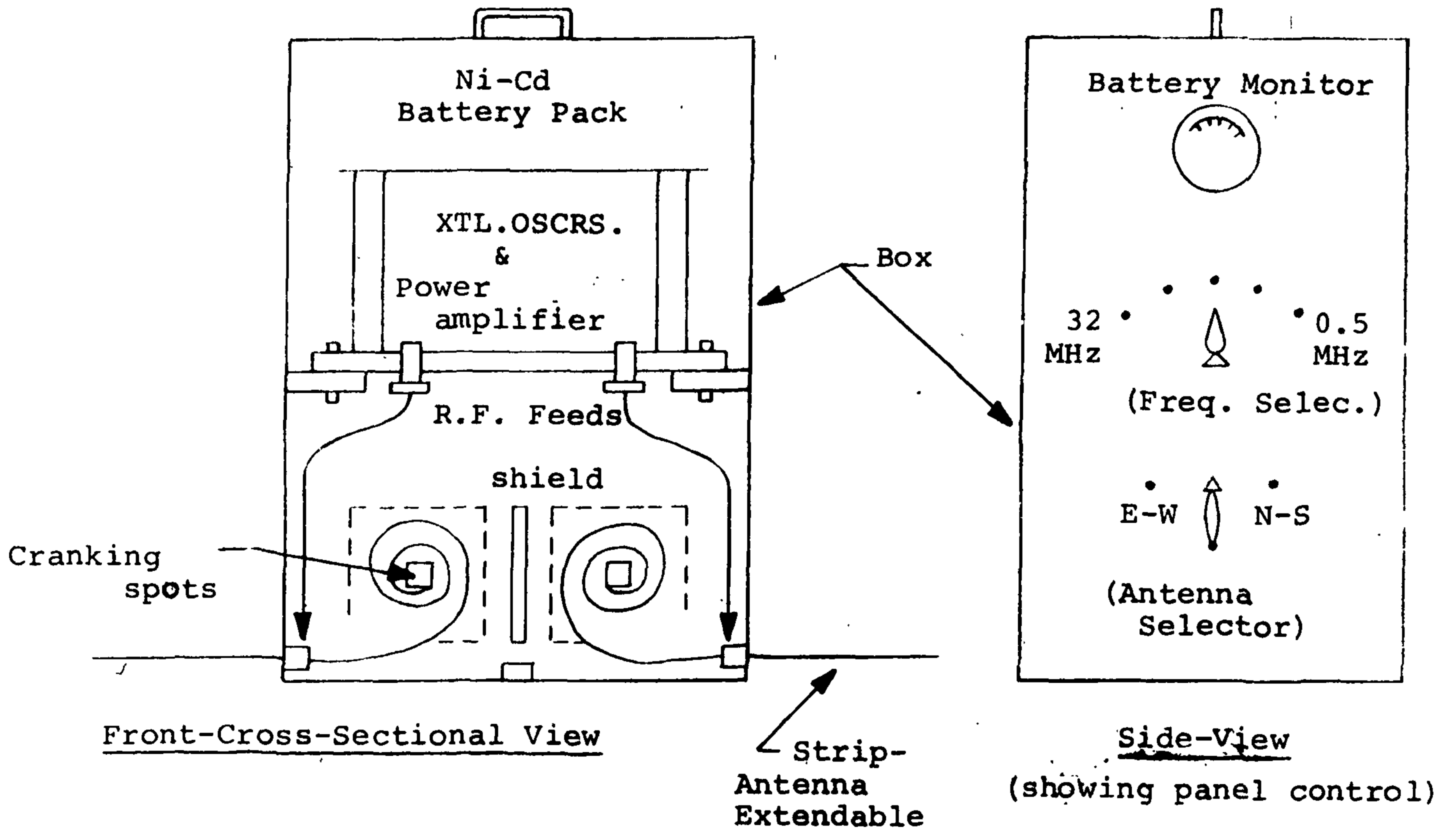


Figure 1. Strip-Configuration Dipole Antenna

Figure 2. Packaged-Version of Extendable Strip-Configuration Antenna/Transmitter System for Glacier-Site SEP Experimentation



Notes:

(1) Box size ≃1.5 cubic feet.

(2) Strip-antenna extendable to resonant length at each discrete frequency of operation: length markers printed on strip-antenna.

MEMO NO. VIII

ADDITIONAL ASPECTS OF MULTIFREQUENCY TRANSMITTING LINEAR-ANTENNA SYSTEM FOR SEP EXPERIMENT USING INSERTED FILTER APPROACH

I.1. SUMMARY

In continuation with the memo dated 11/30/70, other cannonical configurations of multifrequency (0.5 to 32 MHz in harmonic steps) center-fed linear dipole antenna system along with circuit parameters are shown in Figures 1, 2 accomodating the case of dielectric loading of antenna elements due to lunar half-space. The radiation efficiency has been particularly investigated at 0.5 MHz for different parameters and the results are tabulated below. These results are based on using first-order approximation antenna equations, typical quality factor of coils (≈200), lossless capacitors, no mutual coupling effects and loss tangent of lunar surface material being negligible. (It may be feasible to fabricate the strip configuration antenna from skin-depth metalized cloth; making the transmitting antenna system mechanically lightweight, flexible for packaging, etc.)

	Antenna Constraints	Radiation Efficiency at 0.5 MHz for 70 meters long, #24 Copper Wire Antenna	Radiation Efficiency at 0.5 MHz for 70 meters long, 1.25" Width Strip Antenna	Radiation Efficiency at 0.5 MHz for 140 meters long #24 Copper Wire
Unloaded	(i.e. Free Space)	8.8%	16.2%	29.4%
Loaded	(Effective Dielectric $\epsilon_{re} = 5.5$)	35.6 %	69%	High

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	Antenna Constraints	Radiation Efficiency at 0.5 MHz for 70 meters long, #24 Copper Wire Antenna	Radiation Efficiency at 0.5 MHz for 70 meters long, 1.25" Width Strip Antenna	Radiation Efficiency at 0.5 MHz for 140 meters long #24 Copper Wire
Unloaded	(i.e. Free Space)	8.8%	16.2%	29.4%
Loaded	(Effective Dielectric $\epsilon_{re} = 5.5$)	35.6 %	69%	High

Some of the key problem areas anticipated in these configurations are

(1) Coupling effects between collinear radiating elements and between deployed antennas.

(2) Low VSWR of filters terminating the radiating sections.

(3) Arbitrariness about the effective dielectric constant value of dielectric half-space; this effects radiating efficiency of all the radiating elements.

Forthcoming sections discuss the aspects mentioned above.

I.2 LISTING OF VARIOUS CIRCUITS PARAMETERS AND FORMULATIONS

Various circuit parameters and formulations used in the ensuing calculations are listed here for ready reference.

With reference to Figure 1 of the multifrequency transmitting antenna, the total input impedance looking into feed terminals AA' is given as:

$$Z_{AA'} = Z_s + Z_f + Z_a \pm Z_m \qquad (1)$$

where

$$Z_s = R_r \pm jX_s = \text{radiative impedance of antenna.}$$

To a first order approximation, the real and imaginary terms (R_r, X_s) of radiative impedance (Z_s) of a short dipole are given by;

R_r = radiation resistance for free space dipole antenna

$$\simeq 197.4 \times \left(\frac{\ell}{\lambda_0}\right)^2 \Omega \qquad (2)$$

$\lambda_0 \rightarrow$ Free space wavelength

$\ell \rightarrow$ Total length of dipole antenna

$R_{r\varepsilon}$ = radiation resistance for effective dielectric loaded antenna

$$\simeq \frac{197.4}{\sqrt{\varepsilon}} \times \left(\frac{\ell}{\lambda_\varepsilon}\right)^2 \Omega \qquad (3)$$

$\lambda_\varepsilon \rightarrow$ Wavelength in effective dielectric medium

$|X_s|$ = radiation reactance for free space dipole antenna

$$= 120\ (2.3 \log \frac{\ell}{r} - 1) \cot \frac{\beta_0 \ell}{2}\ \Omega \qquad (4)$$

$\beta_0 = \frac{2\pi}{\lambda_0}$ = free space propagation constant

r = radius of antenna

$|X_{s\varepsilon}|$ = radiation reactance for effective-dielectric loaded antenna

$$= \frac{120}{\sqrt{\varepsilon}} (2.3 \log \frac{\ell}{r} - 1) \cot \beta_\varepsilon \frac{\ell}{2}\ \Omega \qquad (5)$$

$\beta_\varepsilon = \frac{2\pi}{\lambda_\varepsilon}$ = effective dielectric propagation constant

(Equations (2) to (5) pertain to open-circuit termination of the radiating elements.)

Z_f = Impedance due to filter section; assuming lossless capacitor

$$= \frac{R|X_C|^2 - j\left[\frac{L}{C}(|X_L| - |X_C|) + R^2|X_C|\right]}{R^2 + \left[|X_L| - |X_C|\right]^2}\ \Omega \qquad (6)$$

L,C are inductance and capacitance; R is ohmic loss of the inductor; X_L, X_C are reactances.

$$|Z_f| = \frac{L}{CR} \rightarrow @\ \omega = \omega_0, \text{ where } \omega_0 = \frac{1}{\sqrt{LC}} \qquad (7)$$

$$Z_f = R_1 + jX_1 \ @ \ \omega<\omega_0 \tag{8}$$

$$= R_2 - jX_2 \ @ \ \omega>\omega_0 \tag{9}$$

Z_a = Skin effect impedance

$$= R_a + jX_a$$

$$|R_a| = |X_a| \triangleq \frac{1}{R_S\delta} = 3.27 \times 10^{-6} \times \frac{\sqrt{f}}{d} \text{ ohms/meter} \tag{10}$$

$f \rightarrow$ frequency in hertz

$d \rightarrow$ diameter of copper wire in inches.

Z_m = mutual impedance between radiating elements

$$= R_m \pm jX_m \tag{11}$$

The radiation efficiency of antenna can be defined as

$$\eta \triangleq \frac{R_r \text{ or } R_{r\varepsilon}}{R_e[Z_{AA'}]} \quad \text{or} \quad \frac{R_r \text{ or } R_{r\varepsilon}}{|Z_{AA'}|} \tag{12}$$

with all reactances tuned out. (first form); for untuned antenna (second form)

$R_e[Z_{AA'}]$ = Real part of driving point impedance at terminals AA';which implies that provision is made to completely tune out the antenna circuit reactances.

Table 1 lists the various parameters used in the forthcoming computations.

Table 1. EFFECTIVE WAVE LENGTHS AND ELECTRICAL LENGTH OF ANTENNAS

(Average Dielectric Constant of lunar half-space is taken 10; so that effective dielectric constant (ε_{re}) seen by antenna system is 5.5)

f_0 (Excitation Frequency)	λ_0 (Free-Space Wavelength)	λ_ε [Wave Length in effective Dielectric Medium (ε_{re}=5.5)]	$\lambda_\varepsilon/2$	$\lambda_f/\lambda_\varepsilon$ (Total normalized length of radiating element)	$\theta = \beta_\varepsilon \frac{\ell_f}{2}$ (Electrical Length of Radiating Elements)
32 MHz	9.38 Meters	4 Meters approximately	2 Meters	0.5	90°
16	18.75 "	8 "	4 "	0.5	90°
8	37.5 "	16 "	8 "	0.5	90°
4	75 "	32 "	16 "	0.5	90°
2	150 "	64 "	32 "	0.5	90°
1	300 "	128 "	64 "	0.547	98.5°
0.5	600 "	256 "	128 "	0.274	49.2°

I.3 RADIATION EFFICIENCY COMPUTATIONS FOR 0.5 MHZ RADIATING ELEMENT OF THE ANTENNA SYSTEM

For the proposed multifrequency transmitting antenna system (Fig.1), radiating elements from 32 MHz to 1 MHz are about half wave long dipoles and therefore, maintain a higher level of radiation efficiency. However, 0.5 MHz radiating element being electrically short requires investigation about its radiation efficiency under various parameter conditions. It is assumed that lunar material has negligible loss tangent for the calculations made in the following cases of interest:

I.3.A <u>Radiation Efficiency for the case</u>: Free Space and #24 copper wire

ℓ = 70 meters: total length λ_0 (free space) = 600 meters @0.5MHz
Antenna configuration is #24 copper wire; diameter 0.020";

For this case, the input impedance (Z_{AA}) of antenna from Fig. 1 is

$$Z_{AA'} = Z_S + 2[Z_{F1}+Z_{F2}+Z_{F3}+Z_{F4}] + Z_a + 2 \times Z_{coil} \tag{13}$$

where:

$Z_S\Big|$ = radiative impedance of antenna from Eqs.(2)&(4)

$$\left\{\begin{array}{l} \ell/\lambda \simeq 0.116 \\ \ell/r = 275520 \\ \theta = 20°48' \end{array}\right\}$$

$$= 197.4\times\left(\frac{\ell}{\lambda}\right)^2 - j\,120[2.3 \log 275520-1]\cot 20°\,48'$$

$$= 2.66 - j\,3730\ \Omega \tag{14}$$

Z_a = skin effect impedance of antenna from (10)

$$=70\times3.27\times10^{-6}\times\frac{\sqrt{0.5\times10^{6}}}{.020} = 8.1 \text{ ohm} \qquad (15)$$

$2[Z_{F_1}+Z_{F_2}+Z_{F_3}+Z_{F_4}]\Big|$ = total impedance of filter circuits

for Q=200

$$\simeq 2[\frac{20}{200}\times4]+j\ 2X[\Delta_1+\Delta_2+1+5]$$

$$= 0.8 + j\ 12\ \Omega \qquad (16)$$

$2xZ_{coil}$ = total impedance of tuning coils

$$= (\frac{3730-12}{200}) + j\ (3730-12)$$

$$=(18.59 + j\ 3718)\ \Omega \qquad (17)$$

From (13) through (17)

$$Z_{AA'} = [2.66-j\ 3730] + [0.8+j12]+8.1+18.59+j3718$$

$$= 30.16\ \Omega \qquad (18)$$

η(Radiation Efficiency)$\Big|$ = $\frac{2.66}{30.16}\times 100 \simeq 8.8\ \%$

@ 0.5MHz antenna
Free Space
#24 copper wire

I.3.B Radiation Efficiency for the Case: Free Space and Strip Antenna

$$\left[\begin{array}{l} \ell = 70 \text{ meters} \\ \omega = \text{width of strip } 1.25'' \text{ made from copper metalized cloth} \\ \lambda_0 = 600 \text{ meter at } 0.5\text{MHz} \end{array}\right]$$

Equation (13) for $Z_{AA'}$ holds in this case also; wherein,

$$Z_S\Big| = \text{from (2) \& (4)} = 2.66 - j120[9.1-1] \times 2.63$$
$$= (2.66 - j2560)\ \Omega \quad (19)$$

$$\left\{\begin{array}{l} \ell/\lambda = .116 \\ \ell/r = 8840 \\ \Theta = 20°,48' \end{array}\right\}$$

and from (16),

$$2[Z_{F_1} + Z_{F_2} + Z_{F_3} + Z_{F_4}]\Big| \simeq (0.8 + j12)\ \Omega$$

for Q=200

$$Z_a = \text{from (10)} \simeq 0.26 \text{ ohm} \quad (20)$$

$$2 \times Z_{coil} = \frac{2560-12}{200} + j(2560-12) = (12.74 + j2548)\ \Omega \quad (21)$$

From (13),(16) and (19) through (21):

$$Z_{AA'} = (2.66-j2560)+[0.8 + j12] +0.26 + [12.74 + j2548]$$
$$= 16.46\ \Omega \quad (22)$$

$$\eta\,(\text{Radiation Efficiency})\Big| = \frac{2.66}{16.46} \times 100 \approx 16.2\% \qquad (23)$$

@ 0.5 MHz; free space

1.25" wide strip antenna

I.3.C. Radiation Efficiency for the Case: Lunar Dielectric Loading: $\varepsilon_{re}=5.5$ #24 copper wire

$$\begin{bmatrix} \ell = 70 \text{ meters} \\ \lambda_\varepsilon \simeq 256 \text{ meters} \\ \#24 \text{ copper wire} \end{bmatrix}$$

Various terms of Equation (13) for $Z_{AA'}$ are obtained as below:

$$Z_S\Big| = \text{from } (3)\&(5) = 197.4 \times (0.274)^2 - j\frac{120}{2.35}[12.5-1]\times 0.862$$

$$\left\{\begin{array}{l} \text{for } \dfrac{\ell}{\lambda_\varepsilon} = 0.274 \\ \theta = 49°\,15' \end{array}\right\}$$

$$= (6.25 - j505)\text{ ohm} \qquad (24)$$

$$Z_a = \qquad \text{from } (10) = 8.1 \text{ ohm} \qquad (15)$$

and from (16),

$$2\times(Z_{F_1}+Z_{F_2}+Z_{F_3}+Z_{F_4})\Big| = 0.8 + j12 \text{ ohm} \qquad (16)$$

for Q=200

$$2\times Z_{coil} = \frac{505-12}{200} + j(505-12) = (2.46 + j493)\,\Omega \qquad (25)$$

From (13),(24), and (25),

$$Z_{AA'} = [6.25-j505]+[0.8+j12]+8.1+[2.46+j493] = 17.61 \quad (26)$$

$$\simeq \eta \text{ (Radiation Efficiency)} = \frac{6.25}{17.61} \times 100 \simeq 35.6\% \quad (27)$$

at 0.5 MHz antenna
dielectric loaded
(ε_{re}=5.5)
#24 copper wire

I.3.D. Radiation Efficiency for the Case: Lunar Dielectric Loading, $\varepsilon_{rc}=5.5$

$$\left[\begin{array}{l} \ell = 70 \text{ meters} \\ \lambda_\varepsilon = 256 \text{ meters} \\ \text{Strip configuration antenna (width 1.25")} \end{array}\right]$$

Various terms of input impedance $Z_{AA'}$ from (13) are evolved as below.

$$Z_S\Big| = \text{from (3)\&(5)} = 197.4 \times (0.274^2) - j\frac{120}{2.35}[9.1-1] \times .862$$

$$\left\{\begin{array}{l} \frac{\ell}{\lambda_\varepsilon} = 0.274 \\ \frac{\ell}{r} = 8840 \\ \theta = 49^\circ\ 15' \end{array}\right\} = (6.25 - j356)\ \Omega \quad (28)$$

$$Z_a = \text{from (10)} = 0.26\ \Omega$$

$$2 \times (Z_{F_1}+Z_{F_2}+Z_{F_3}+Z_{F_4}) \simeq (0.8 + j12)\ \Omega$$

$$? + j(356-12) = (1.72 + j344)\ \Omega \quad (29)$$

From (13),(28),(29), etc.

$$Z_{AA'} = (6.25-j356)+(.8+j12)+0.26+(1.72+j344) = 9.03 \qquad (30)$$

η(Radiation Efficiency) @ 0.5 MHz antenna dielectric loading (ε_{re}=5.5) strip antenna width = 1.25" $= \frac{6.25}{9.03} \times 100 \simeq 69\%$ (31)

I.4. LONGER TRANSMITTING ANTENNA SYSTEM OF TOTAL LENGTH 140 METERS

One possible multifrequency antenna configuration for 140 meters long wire is shown in Figure 2 for the case of dielectric loading dielectric constant (ε_{re}=5.5). It can be seen that all the radiating elements are about half-wavelength long and therefore, maintain a higher level of radiation efficiency including 0.5 MHz antenna wherein $\ell/\lambda_{\varepsilon}$ is about 0.556.

However, in the case where dielectric loading effect is negliglble, the radiation efficiency @ 0.5 MHz will still be a reasonably acceptable level for 140 meters long antenna as shown by the following computations. With reference to Figure 2, the driving point impedance ($Z_{BB'}$) at terminal BB' for the free space case @ #24 copper wire antenna,

$$Z_{BB'} = Z_S+2x[Z_{F_1}+Z_{F_2}+Z_{F_3}+Z_{F_4}+Z_{F_5}] \quad Z_a + 2xZ_{coil} \qquad (32)$$

$$Z_S\Big| = \text{from Eqs.}(2)\&(4) = 197.4\text{x}0.053 - j120[2.3\log\frac{\ell}{2} - 1)\cot 41° \, 4'$$

$$\left\{\begin{array}{l} \frac{\ell}{\lambda_0} = 0.23 \\ \frac{\ell}{r} = 54,8800 \\ \theta = \beta\frac{\ell}{2} = 41°4' \end{array}\right\} = (10.5 - j1640)\ \Omega \tag{33}$$

$$Z_a = \text{from (10) for \#24 copper wire} = 16.2 \text{ ohm} \tag{34}$$

$$2\text{x}\ [Z_{F_1} + Z_{F_2} + Z_{F_3} + Z_{F_4} + Z_{F_5}] \simeq 2\text{x}[.5] + j\text{x}2\text{x}[\Delta_1 + \Delta_2 + \ldots + 5 + 13]$$

$$= (1 + j36)\ \Omega \tag{35}$$

$$2 \times Z_{coil} = [\frac{1640-36}{200}] + j1604 = (8 + j1604)\ \Omega \tag{36}$$

$$Z_{BB'} = [10.5 - j1640] + (1 + j36) + 16.2 + (8 + j1604) = 35.7\ \Omega \tag{37}$$

$$\eta(\text{Radiation efficiency}) = \frac{10.5}{35.7} \times 100 \simeq 29.4\,\% \tag{38}$$

for 170 meter long dipole
antenna in free space
using #24 copper wire

I.5 DISCUSSION OF PROBLEM AREAS

The effect of problem areas, encountered in the satisfactory performance of a multifrequency antenna system, can minimized through combined efforts in the areas of analysis, developments of components and circuits, Model studies, and glacier site experimentation. A brief discussion of some of the problem areas is made here:

I.5.A. Coupling Effects between Collinear Radiating Elements

Mutual impedance due to coupling effects needs analytical investigation as well as empirical determination based on Model studies and glacier site experimentation. One possible solution, to reduce the coupling effects, may be in choosing physical length of each radiating segment governed by the condition,

$$\ell_f/\lambda_f \leq 0.250 \tag{39}$$

where:

ℓ_f = total physical length of each dipole at its transmitting frequency f

λ_f = excitation wavelength.

This approach percludes each subsequent antenna-segment from the near-field effects of the preceding antenna-segment.

Based on this criteria, a multifrequency antenna system was proposed in the memo dated 11/30/70. A complete chain of caluclations was made including radiation efficiencies based on Q of filters about 300. The overall consequence of designing the antenna systems using the criteria ($\ell_f/\lambda_f \leq 0.25$) will be that radiation efficiency level at all the frequencies will get reduced including the case reported in the Summary section I.1.

I.5.B <u>R.F. Power Leakage through Filters Terminating the Radiating Sections</u>

From transmission-line theory considerations, the antenna can be regarded as a transmission line of average characteristic impedance (Z_{av}) which can be derived in the form,

$$Z_{av} = \sqrt{\frac{\mu}{\varepsilon}}\left(\log\frac{\ell}{r} - 1\right) = \frac{120\pi}{\sqrt{\varepsilon_r}}\left[\log\frac{\ell}{r} - 1\right] \qquad (40)$$

where:

ε_r = dielectric constant of medium embedding the antenna.

The input impedance (Z_i) of a lossless transmission line of electrical length $\beta\frac{\ell}{2}$ terminated in load Z_L is given as

$$Z_i = \quad = Z_{av}\frac{1 + j\frac{Z_{av}}{Z_L}\tan\beta\frac{\ell}{2}}{\frac{Z_{av}}{Z_L} + j\tan\beta\frac{\ell}{2}} \qquad (41)$$

For a typical antenna, $Z_L \rightarrow \infty$ (open circuit condition); therefore, Z_i in (41) reduces to the form below giving the reactive impedance of the antenna within first order approximations:

$$|Z_i| = |X_S| \simeq Z_{av} \cot\beta\frac{\ell}{2} = \frac{120\pi}{\sqrt{\varepsilon_r}}[\log \frac{\ell}{r} - 1] \cot \beta\frac{\ell}{2} \qquad (42)$$

However, the case of dipole antenna terminated in filter circuits (LCR elements Figs. 1&2) needs special attention because of low VSWR conditions due to small ratio between Z_L and Z_{av} values. This may result in leakage of r.f. power to the subsequent segment of radiating wires. Equation (41) supports the above possibility, because, for the case of $Z_L \not\gg Z_{av}$, it adds a real component in Z_i: i.e. from (41),

$$Z_i^N = \frac{Z_i}{Z_{av}} \simeq \frac{1+j\frac{Z_{av}}{Z_L} \tan\beta\frac{\ell}{2}}{j \tan\beta\frac{\ell}{2}} = \frac{Z_{av}}{Z_L} - j \cot\beta\frac{\ell}{2}$$

$$Z_i = \frac{Z_{av}^2}{Z_L} - jZ_{av} \cot\beta\frac{\ell}{2}$$

$$Z_i = r_i - j Z_{av} \cot\beta\frac{\ell}{2} \qquad (43)$$

Term r_i describes the leakage loss due to low VSWR prevailing at the antenna-filter circuit interface. The magnitude of the r.f. power leakage problem can be realized through the numbers quoted in Table II. The governing equations for Table II numbers are listed here:

$$\rho = \text{VSWR} \triangleq \frac{Z_{L_T}}{Z_{av}} \quad \text{or} \quad \frac{Z_{av}}{Z_{L_T}} \tag{44}$$

$$\Gamma = \text{Rejection Coefficient} \triangleq \frac{Z_{L_T} - Z_{av}}{Z_{L_T} + Z_{av}} = \frac{\rho-1}{\rho+1} \tag{45}$$

R.L. = Return Loss; measure of reflection capability of the termination $\triangleq \frac{P_r}{P_i} = |\Gamma|^2$ (46)

where

P_r, P_i = reflected and incident power respectively.

T.L. = Transmission Loss; measure of transmission characteristics of the termination.

$\triangleq \frac{P_t}{P_i} = [1 - |\Gamma|^2]$ for lossless termination case (47)

P_t = transmitted (or leakage) power

$|Z_L|$ = filter circuits impedance at resonance

$= [\frac{L}{CR} \times 2]$ (48)

$|Z_{L_T}|$ = total load across dipole antenna (assuming the equivalent circuit model being correct)

$= Z_L + Z_{av}$ (49)

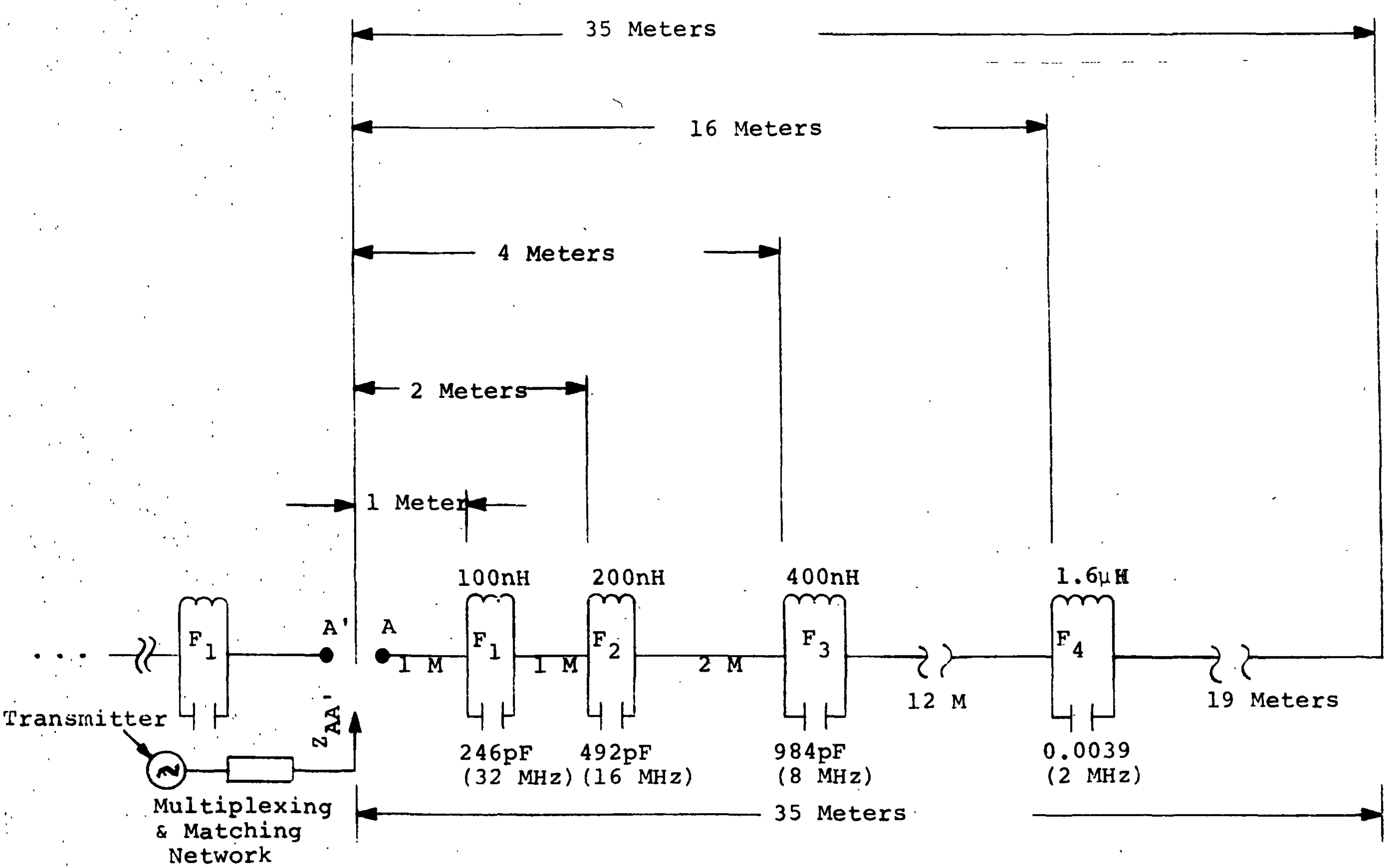
TABLE II R.F. LEAKAGE POWER THROUGH FILTERS (BASED ON EQUATIONS 44 THROUGH 49)

CASE	Z_L (total filter ckt. imped.)	Z_{AV} (Average char. imped. of antenna)	Z_{LT} (total load imped.)	ρ (VSWR)	$\|\Gamma\|$ (Reflection Coefficient)	R.L. (Return Loss)	T.L. (Transmission Loss)
I. Figs.1&2 32 MHz,#24 copper wire antenna & dielectric loading,5.5	8140 ohms	400 ohms	8540 ohms	21.4	≈0.91	≈0.85dB (82.8%)	≈7.4dB (18%)
II. Same as case I. above but unloaded antenna	8140 "	940 "	9080 "	9.67	0.81	≈1.8dB (65.6%)	4.6dB (34.4%)
III. Figs.1&2 8MHz,#24 copper wire antenna & dielectric loading,5.5	8140 "	476 "	8616 "	18.1	≈0.9	0.9dB (81%)	7.3dB (19%)
IV. Same as Case III. above but unloaded antenna	8140 "	1118 "	9258 "	8.3	0.78	≈ 2dB (60.8%)	≈4.3dB (39.2%)

From Table II data, it can be seen that especially for the cases (II) & (IV) of unloaded transmitting antenna, a considerable fraction of r.f. power leaks through filter sections.This can excite the consecutive wire segments resulting in a multilobe radiation pattern.

The r.f. leakage can be suppressed through development of very high Q inductive coils. This will enable a choice between larger inductance (L) values in the filter circuit while keeping the ohmic loss low. From (48) & (44), larger inductance implies $|Z_L| >> |Z_{av}|$, and therefore, high VSWR and minimum r.f. power leakage. Alternatively, minimizing the characteristic impedance of the antenna will also accomplish high VSWR; however, for the wire configuration antennas (Figs. 1,2) it is not practically feasible.

Figure 1. Possible Configuration of Multifrequency Antenna System Assuming Lunar Half-Space Loading of Effective Dielectric Constant ($\varepsilon_{er} = 5.5$); Total Antenna Length, 70 Meters



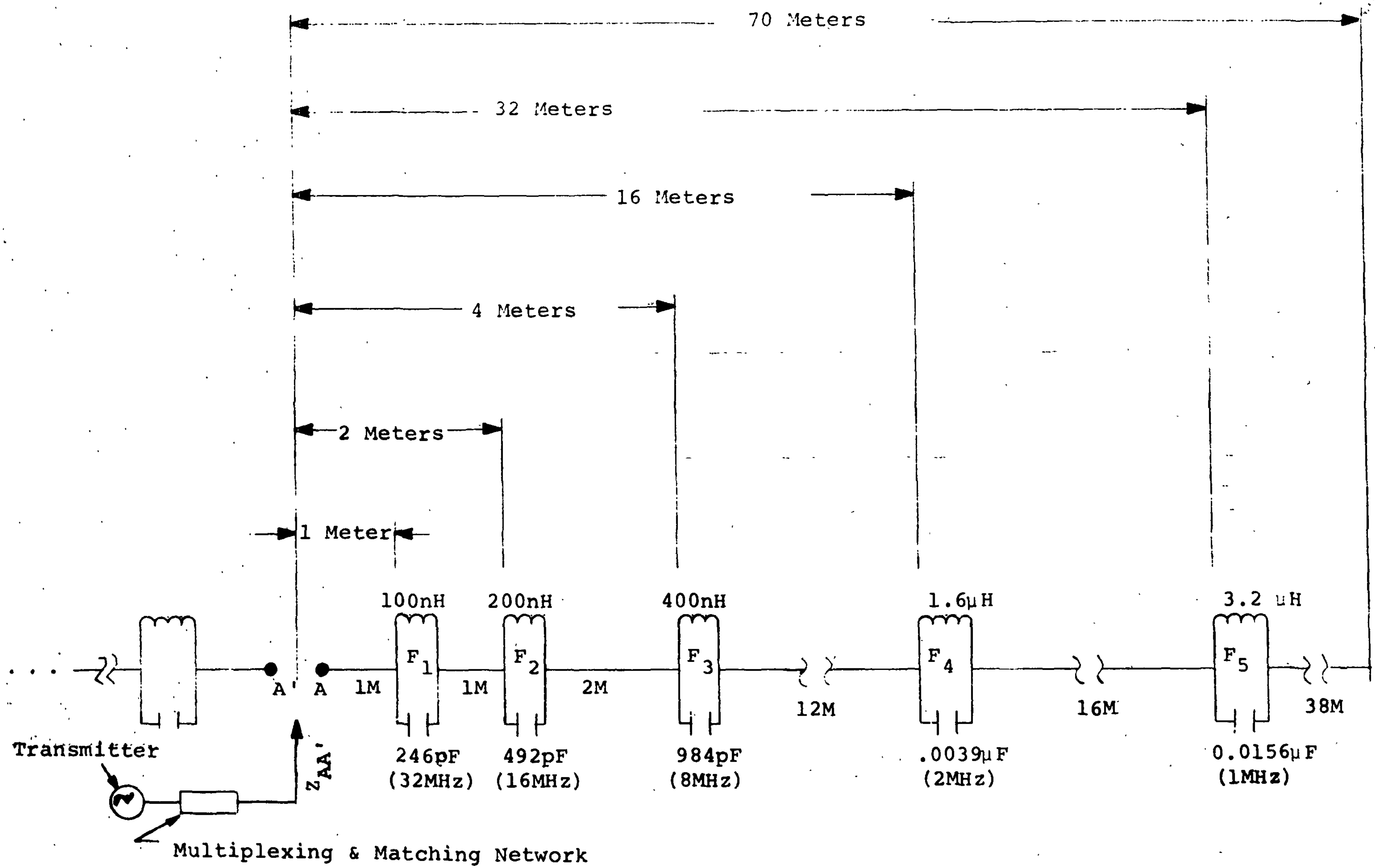


Figure 2. Possible Configuration of 140 Meters Long Transmitting Antenna System for the Case of Lunar Half-Space Loading of Effective Dielectric Constant $\varepsilon_{er} = 5.5$